PRELIMINARY DESIGN OF A FREE VORTEX AXIAL FLOW TURBINE

Victor Endo

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Submitted to the Department of Ocean Engineering on May 12, 1977 in partial fulfillment of the requirements for the degrees of Ocean Engineer and Master of Science in Naval Architecture and Marine Engineering.

ABSTRACT

The thesis covers the mechanical, thermodynamics, and aerodynamics of designing a free vortex axial flow turbine with the aid of a digital computer, It uses the Improved Ainley-Mathieson Performance Estimation Method to determine the aerodynamic pressure losses so off-design and design point calculations can be conducted to produce performance curves. It also gives physical and thermodynamic properties of the turbine.

Thesis Supervisor: Alexander Douglas Carmichael

Title: Professor of Power Engineering

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The author wishes to thank Professor Alexander Douglas Carmichael for his guidance and direction during the period this thesis was written.

The author is very grateful to Dorcas Butler for her patience in typing this thesis without the luxury of having an engineers typewriter or knowing what the funny symbols I misspelled meant. Also to the United States Navy which gave me the opportunity to attend MIT for the past three years.

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The purpose of this thesis is to develop a computer program which can be used in the Preliminary Design of a Free Vortex Axial Flow Turbine. The design plan consists of three main parts. The first will be cycle calculations to determine stage characteristics at each station such as angles, density, temperature, flow areas, etc. The properties from this phase will be used in parts 2 and 3. The second part is to determine mechanical characteristics such as size and weights of turbine parts and stress and vibrational characteristics. The final phase is to determine turbine characteristics at design and off design parameters such as speed, pressure ratio, etc. This last phase is optional since compressible flow tables and gas properties are required and many turbine designers may be more interested in the size and weights than off design characteristics in the preliminary design phase. These three parts are covered in chapters one through three, chapter four will cover the operation of the computer program developed in this text. Appendix one is a list of symbols used in the text, appendix two is a user's guide to the computer program and has an example turbine design which is compared with a design proposed by reference 20. Appendix three is the computer program.

The computer program is set up so it has many options of input variables so that as the designer becomes more knowledgeable

in his design study he can specify more characteristics and have more control over the design output. There are checks in the program to limit poor design properties such as excessive swirl in output, high tip to hub ratios, negative reactions, etc. The computer program can be used to design a constant hub, mean, or tip turbine. The design does not consider the effects of cooling in turbines, since time was not available to incorporate this into the computer program. This limitation mostly affects aircraft gas turbine and aircraft derivative marine gas turbines since these engines operate at high tur- inlet temperatures and cooling is required to allow for a high mean time between failures.

There has been no effort made to prove the relations used in the design calculations. These can be found in basic physics, thermodynamics, and fluid mechanics books.

The notation as to signs of angles in the velocity diagrams will be the same as used in chapter 4 of Gas Turbine Handbook which is reference (3). An illustration is enclosed in chapter 1 of the sign convention and notation used in this text. A deviation from this notation will be used in section (3.2).

Chapter 1

Cycle Calculations

1.1 The basic design of an axial flow turbine starts with the cycle calculations to determine the thermodynamic properties throughout the turbine. The basis of these calculations are from known inlet conditions and assumed design parameters. The computer program is set up so that a minimum number of these parameters must be specified and leaves the option to the designer to more fully specify the design parameters, if he so desires. This chapter intends to show how these basic calculations are carried out and the methods employed to determine the physical properties such as flow area from these design parameters. Figures (1-1), (1-2), and (1-3) show the sign convention and notation that will be used in this chapter. The following are some of the design parameters needed for the cycle calculations; inlet temperature (^{o}R) Toi, turbine inlet pressure (psi) Poi, omega (rpm) Ω, specific heat (btu/lbm ^{o}R) Cp, mass flow (lbm./sec) $\dot{m}$, ratio of specific heat gamma γ, tip radius (ft) r_t, tip to hub ratio (r_t/r_h), desired efficiency η_t, loading coefficient ψ, etc. Appendix two (2) will specify which parameters must be known and which ones are optional.

1.2 Determination of overall turbine parameters from inlet conditions and assumed design parameters.

(a) (1.2-1)

$$\Delta ho_t = \frac{\text{Power (hp) } 550}{mJ\,\eta_t}$$

(1.2-2)

$$Toe = Toi - \frac{\Delta ho_t}{Cp} \; (^{o}R)$$

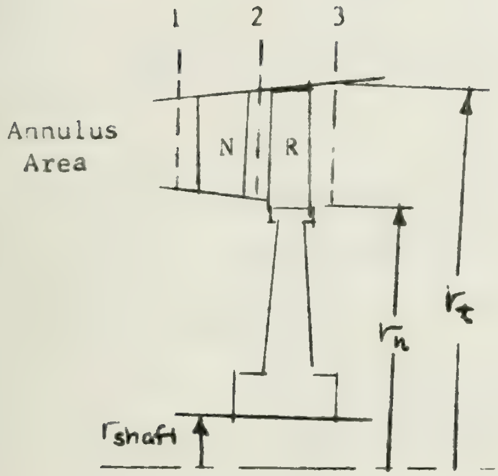


Fig. 1-1 Axial Flow Turbine Stage

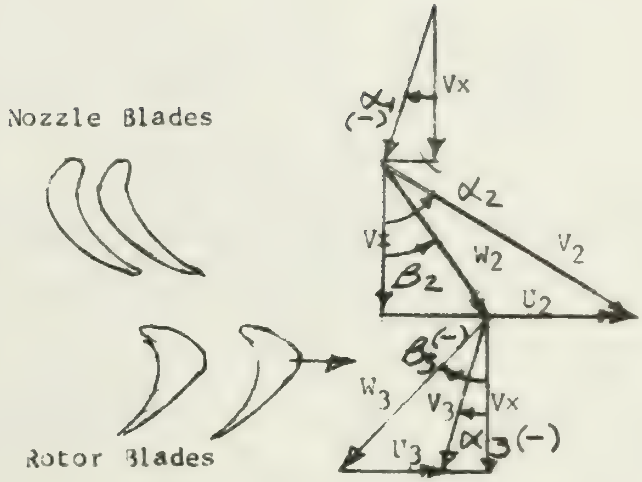


Fig. 1-2 Velocity Diagram

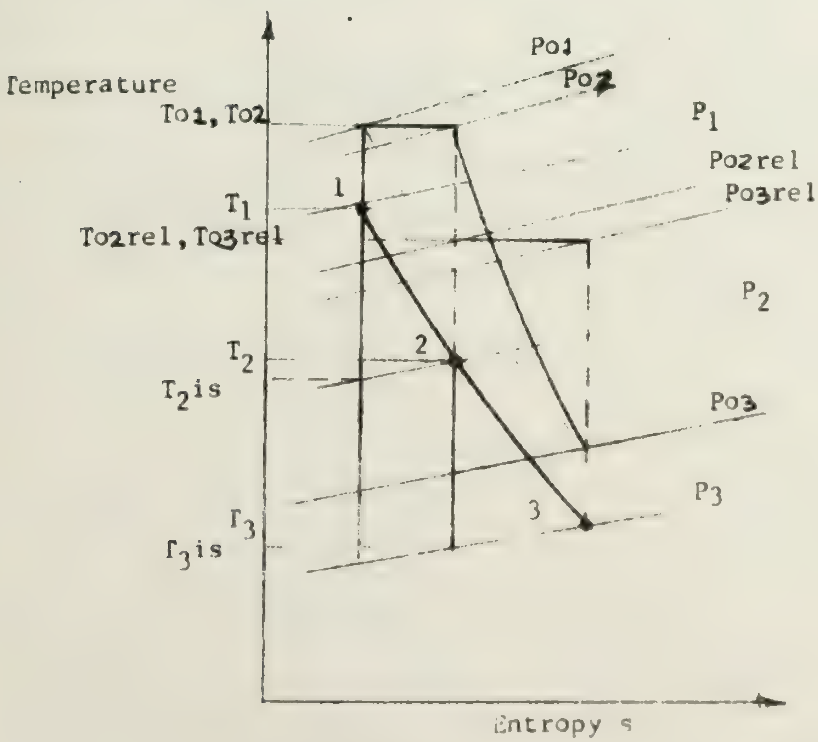


Fig. 1-3 T-S diagram for a Reaction stage

Polytropic Efficiency

$$\eta_p = \frac{\ln(Toe/Toi)}{\ln\left[\frac{(Toe/Toi-1)}{\eta_t} + 1\right]} \qquad (1.2\text{-}3)$$

$$Poe = Poi\ (Toe/Toi)^{\frac{\gamma}{\eta_p(\gamma-1)}} \qquad (1.2\text{-}4)$$

(b) If the pressure ratio were specified instead of output power the following calculations will be performed.

Polytropic Efficiency

$$\eta_p = \frac{\ln\left(1 - \eta_t\left(1-(Poe/Poi)^{\frac{\gamma-1}{\gamma}}\right)\right)}{\ln\left[(Poe/Poi)^{\frac{\gamma}{\gamma-1}}\right]} \qquad (1.2\text{-}5)$$

$$Toe = Toi\ (Poe/Poi)^{\frac{\gamma}{\eta_p(\gamma-1)}} \qquad (1.2\text{-}6)$$

$$\Delta ho = Cp(Toi - Toe) \qquad (1.2\text{-}7)$$

$$\text{Power out} = \frac{\dot{m}\Delta ho\,\eta_t J}{550} \qquad (1.2\text{-}8)$$

(c)

$$\omega = \frac{\Omega(2\pi)}{60} \quad (\text{rad/sec}) \qquad (1.2\text{-}9)$$

$$r_h = r_t/(r_t/r_h) \qquad (1.2\text{-}10)$$

$$r_m = (r_h + r_t)/2 \qquad (1.2\text{-}11)$$

$$U_h = r_h\omega(\text{ft/sec}) \qquad (1.2\text{-}12)$$

$$\Delta ho_{stage} = \frac{U_h V_x (\tan\alpha_2 - \tan\alpha_3)}{g_o J} \tag{1.2-13}$$

$$\psi = \frac{g_o J \Delta ho_{stage}}{U_h^2} \tag{1.2-14}$$

The value of ψ is taken at the hub of the last stage because this is the most critical in the design of a turbine in reference to loading. Normally the value of ψ is from (1.5 - 2.9). The lower value is for lightly loaded stages while the higher is for highly loaded stages. To have no exit swirl ψ must be less than or equal to 2.0.

$$\psi \leq 2.0 \implies \text{(no exit swirl)}$$

for $\alpha_h = 0$

$$R = 1 - \psi/2 \tag{1.2-15}$$

where

$$R = \frac{h_2 - h_3}{ho_1 - ho_3}$$ ratio of change in static enthalpy across the rotor to change in stagnation enthalpy across the stage. (1.2-15a)

With the value of ψ specified, the number of stages required to develop the power out desired can be determined.

$$\Delta ho_{stage} = \frac{\psi U_h^2}{g_o J} \tag{1.2-16}$$

Determining number of stages

$$N = \text{integer } \frac{\Delta ho_t}{\Delta ho_{stage}}$$

If N were specified instead of ψ, the change in enthalpy per stage would be determined.

$$\Delta ho_{stage} = \frac{\Delta ho_t}{N}$$

This program uses a constant change in enthalpy for each stage. If $\psi \leq 2.0$ and $\alpha_h = 0$ the radius of the hub can be determined from equation (1.2-17).

$$r_{he} = \left[\frac{g_o J \Delta h_{o\,stage}}{\omega^2}\right]^{\frac{1}{2}} \qquad (1.2\text{-}17)$$

Another parameter which will be used is $\phi \equiv Vx/U_h$ (flow coefficient). Where Vx is the axial velocity, which is constant in a free vortex turbine. This parameter ranges from 0.4 - 1.3, the higher values are used for aircraft turbines which use high axial velocity for propulsion. In marine and industrial turbines a low value is desired because the energy of the exhaust gases are not recoverable in this form, unless it is used to drive another turbine.

Another parameter that may be specified is the critical Mach number at the exit.

$$M_{crit} \equiv \frac{Vx}{\left[\frac{2}{\gamma+1} g_o R T_{oe}\right]^{\frac{1}{2}}} \qquad (1.2\text{-}18)$$

where R is the gas constant

$$R \equiv Cp(\gamma-1/\gamma)J \qquad (1.2\text{-}19)$$

The Vx is computed exactly

$$Vx = M_{crit} \left[(2/(\gamma+1)) g_o R T_{oe}\right]^{\frac{1}{2}} \qquad (1.2\text{-}18a)$$

If the exit Mach number is specified the turbine exit area is varied until the required area is obtained to give the specified axial velocity Vx. If this number is not specified but the exit area is specified the value of Vx is varied until the required area is achieved.

From the continuity equation for gases

$$Vx = \frac{\dot{m}}{2\pi\int_{r_h}^{r_t}\rho(r)rdr} \qquad (1.2\text{-}20)$$

where

$$\rho(r) = \frac{P(r)}{RT(r)} \qquad (1.2\text{-}21)$$

$$T(r) = To - \frac{V(r)^2}{2CpgoJ} \qquad (1.2\text{-}22)$$

$$P(r) = Po/(To/T(r))^{\frac{\gamma}{\gamma-1}} \qquad (1.2\text{-}23)$$

$$V(r) = \frac{Vx}{\cos(\alpha(r))} \qquad (1.2\text{-}24)$$

where r varies between the hub and tip. If the exit angle is not equal to zero

$$\alpha hub_e = \tan^{-1}\left[(1 - R_{he} - \psi/2)/\phi\right] \qquad (1.2\text{-}25)$$

and for free vortex

$$rV_\theta = rVx(\tan\alpha) = \text{constant} \qquad (1.2\text{-}26)$$

then

$$\alpha(r_e) = \tan^{-1}\left[\frac{r_{he}\tan(\alpha_{he})}{r_e}\right] \qquad (1.2\text{-}27)$$

where re is taken at hub mean, and tip. This calculation is carried out in function program ANGLE. Thus the exit angle has been determined at the hub, mean, and tip radii.

The pressure, density, and temperature calculations are performed in subroutine TP1. The integral calculation is performed in subroutine DENR which uses Simpson's Rule to compute the axial velocity Vx. With the absolute angles $\alpha(r_e)$ determined the relative angles (r_e) can then be determined by equation (1.2-28). This is carried out in function program ANGLEB.

$$\beta(r_e) = \tan^{-1}\left[\tan(\alpha(r_e)) - \frac{U(r_e)}{Vx}\right] \tag{1.2-28}$$

From equation (1.2-15a)

$$R(r_e) = 1 - \frac{\Delta ho_{stage} g_o J}{2(\omega r_e)^2} - \frac{Vx\tan(\alpha_e)}{\omega r_e} \tag{1.2-29}$$

which is computed in function program REACTI. With the exit conditions specified, the properties at station 1 and 2 can then be determined for each stage.

The following properties are now known at the exit of the turbine; Vx, Toe, Poe, $\rho(r_e)$, $P(r_e)$, $T(r_e)$, $\alpha(r_e)$, $\beta(r_e)$, $R(r_e)$, and r_e, where $r_e = r_{hub}, r_{mean}, r_{tip}$.

1.3 Determination of properties at station 1 for stage n where n = 1 . . . . N.

$$To_1 = To3_n + \frac{\Delta ho_{stage}}{Cp} \tag{1.3-1}$$

$$Po1_n = Po3_n / (To3_n / To1_n)^{\frac{\gamma}{\eta p(\gamma - 1)}} \tag{1.3-2}$$

If this is the 1st stage $\alpha_{1n} = 0.0$ where n = 1

If not $\alpha_{1n}(r_c) = \alpha_{3n}(r_c)$ where r_c is the radius which remains constant through out the turbine, ie(constant hub, tip, or mean).

$$\beta_{1n}(r_c) = \tan^{-1}\left[\tan(\alpha(r_c)) - \frac{U(r_c)}{Vx}\right] \qquad (1.3\text{-}3)$$

$$T_{1n}(r_c) = To_{1n} - \frac{V_{1n}^2(r_c)}{2goJCp} \qquad (1.3\text{-}4)$$

$$V_{1n}(r_c) = \frac{Vx}{\cos(\alpha_{1n}(r_c))} \qquad (1.3\text{-}5)$$

$$P_{1n}(r_c) = Po_{1n}/(To_{1n}/T_{1n})^{\frac{\gamma}{\gamma-1}} \qquad (1.3\text{-}6)$$

$$\rho_{1n}(r_c) = \frac{P_{1n}(r_c)}{RT_{1n}(r_c)} \qquad (1.3\text{-}7)$$

which is identical to equations in section for exit of the turbine.

A trial blade height (h) at station 1n will be established.

$$h = \frac{\dot{m}}{2\pi Vx r_c \rho(r_c)} \qquad (1.3\text{-}8)$$

Let delta h = h/10. Now depending on whether the turbine is constant hub, mean, or tip, radius are established at the other radii.

Constant hub;

$$r_{1n}(hub) = r_c \qquad (1.3\text{-}9)$$

$$r_{1n}(mean) = r_c + h/2 \qquad (1.3\text{-}10)$$

$$r_{1n}(tip) = r_c + h \qquad (1.3\text{-}11)$$

Similarly for constant mean or constant tip.

α can then be determined at all radii for station 1 and temperature, pressure, and density can be calculated at all radii in the same manner as was carried out at the exit of the turbine. Then Vx prime can be calculated in the same manner as Vx was calculated.

$$Vx\ prime = \frac{\dot{m}}{2\pi \int_{r_{h_n}}^{r_{t_n}} \rho(r) r\,dr} \tag{1.3-12}$$

When Vx prime = Vx the proper radii has been calculated at station 1. The method employed continuously decreases delta h until convergence is accomplished. This is the same method which was used at the exit of the turbine and will be used in station 2 calculations. The properties of the gas is now determined as per exit of the turbine for station 1. If this isn't the first stage the properties at station 1 are the same as station 3 of the preceeding stage.

1.4 Determination of properties at station 2 for stage n where n = 1 . . . . N

$$To2n = To1n \tag{1.4-1}$$

$$\alpha 2n(r_c) = \tan^{-1}\left[\frac{goJ\Delta ho_s}{Vx\,\omega\, r_c} + \tan(\alpha 3n(r_c))\right] \tag{1.4-2}$$

$$V(r_c) = Vx/\cos(\alpha 2n(r_c)) \tag{1.4-3}$$

$$T2n = To2n - V(r_c)^2/2goJCp \tag{1.4-4}$$

$$P2n \approx P1n(T2n/T1n)^{\frac{\gamma}{\eta p(\gamma-1)}} \tag{1.4-5}$$

which is an approximation from figure (1-3), where the actual pressure is determined from pressure loss data as will be covered in Chapter 3.

$$Po2n = P2n(To2n/T2n)^{\frac{\gamma}{\gamma-1}} \tag{1.4-6}$$

$$\rho 2n = \frac{P2n(r\ )}{RT2n(r)} \tag{1.4-7}$$

These calculations are accomplished in subroutine TPD2 to determine temperature, pressure,and density at station 2. The calculations are carried out in the same manner as station 1 calculations , to determine the gas properties and radii at station 2. The calculations are then carried out at station 1 of the next stage(ie; n = n-1 until properties at all stations and positions have been computed for all stages.)

1.5 Having solved for gas properties at all stations and positions and having flow areas and gas angles the relative stagnation temperature, and the relative Mach numbers for stators and rotors can be calculated.

$$To2_{rel} = T_2 + \frac{W^2}{2goCpJ} \qquad (1.5\text{-}1)$$

$$M_{nozzle\ inlet} = \left[\left(To1n/T1n\right) - 1\right] \frac{2}{\gamma - 1}\right]^{\frac{1}{2}} \qquad (1.5\text{-}2)$$

$$M_{nozzle_{exit}} = \left[\left(To2n/T2n\right) - 1\right] \frac{2}{\gamma - 1}\right]^{\frac{1}{2}} \qquad (1.5\text{-}3)$$

$$M_{rotor_{inlet}} = \left[\left(To2n_{rel}/T2n\right) - 1\right] \frac{2}{\gamma - 1}\right]^{\frac{1}{2}} \qquad (1.5\text{-}4)$$

$$M_{rotor_{exit}} = \left[\left(To3n_{rel}/T3n\right) - 1\right] \frac{2}{\gamma - 1}\right]^{\frac{1}{2}} \qquad (1.5\text{-}5)$$

These calculations are carried out at each stage. The following parameters have been determined at all stations of the turbine; temperature, pressure, density, flow area, absolute and relative angles, Reaction, relative Mach numbers, and the axial velocity Vx. These properties will be used to determine the mechanical aspects of the Turbine design and be used in performance estimation.

Chapter 2

Mechanical Design of an Axial Flow Turbine

2.1 In this chapter the mechanics of the program and assumptions made to design nozzle and rotor blades, and the turbine disc will be discussed.

2.2 Having the gas properties and flow angles throughout the turbine the blade angles can be calculated for the turbine. The criteria used in establishing the blade angles is the loss data provided by figure (2-2) and (2-3) based upon Ainley Mathieson method of performance estimation. As can be seen for reaction blades in figure (2-2) the incidence angles can vary from -15 to + 15 without much of an increase in profile loss Yp. In actual construction this large variation can allow for a decrease in twist in the blade from hub to tip normally required in free vortex blades. For the computer program, selection of blade angle, at the inlet of the blade is for zero incidence at design point.

Figure (2-3) shows how blade exit angle varies with gas angle there is also a correction for Mach number. For Mach numbers less than 0.5 the values given by figure (2-3) will be used, for values greater than Mach 1 the blade angles will be equal to gas angles while for values between Mach 0.5-1.0 a linear variation will be assumed as is shown in figure (2-4). The calculation of these blade angles are carried out in subroutine Blade, which also will be used to determine gas angles when blade angles are known for off-design calculations in chapter 3. There is an additional correction for blades

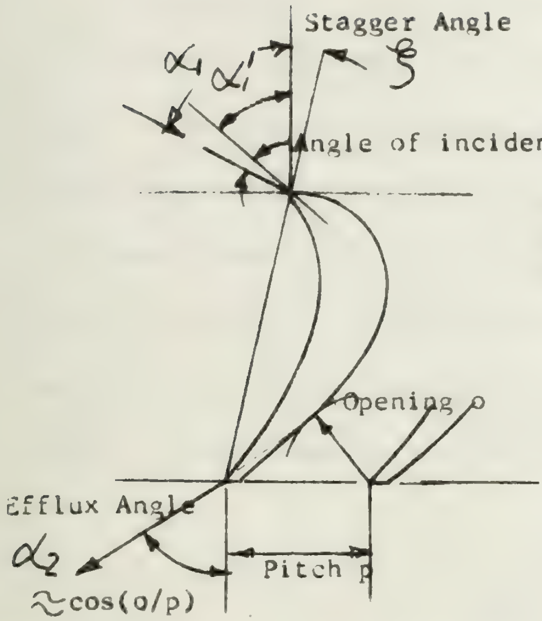


Figure 2-1. Conventional Blade Profile

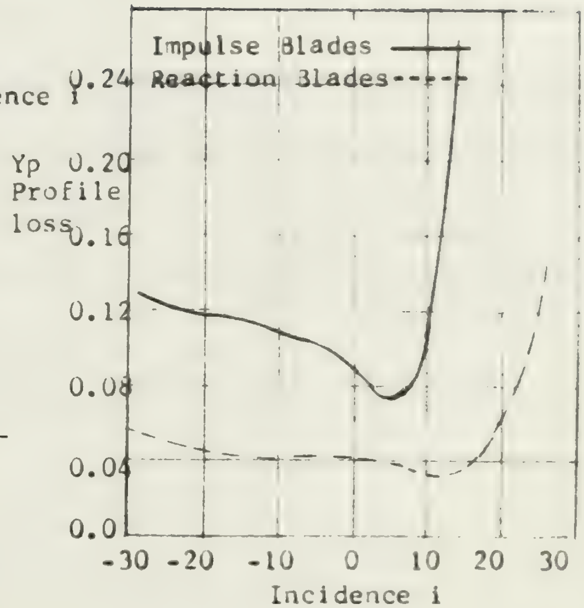


Figure 2-2. Variation in profile loss with incidence angle(From D.G.Ainley and G.C.R.Mathieson(1))

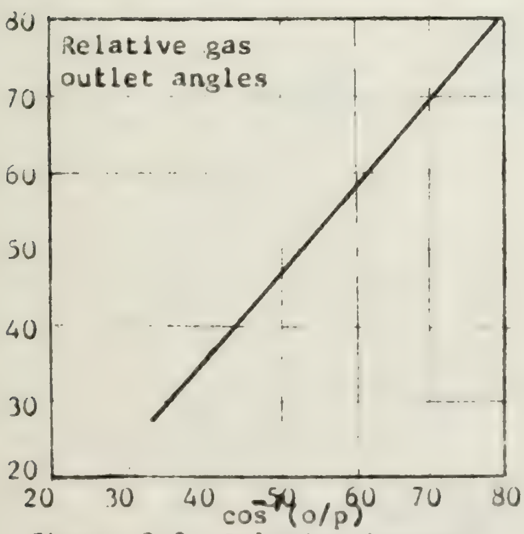


Figure 2-3. Relation between gas and blade angles (From D.G.Ainley and G.C.R.Mathieson(2))

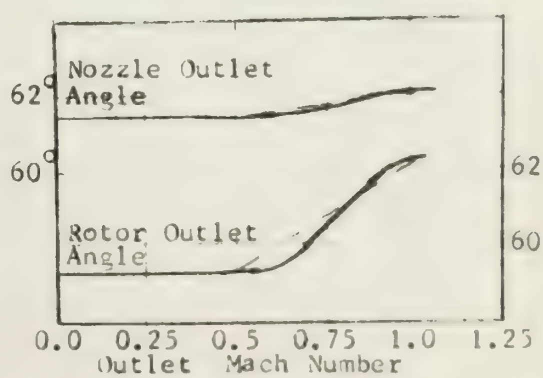


Figure 2-4. Angle variation with mach number(From D.G.Ainley and G.C.R.Mathieson(2))

with a curved back trailing edge in reference (2) but this will not be applied in the computer program.

2.3 The computer program can now determine the ideal pitch to chord ratio P/C, blade chord (C), aspect ratio H/C, bending and centrifugal stresses, number of blades, 1st bending frequency, and weight of blades. As will be shown in this section all these parameters are interrelated and they all help determine each other.

2.3a Centrifugal Stress Calculations

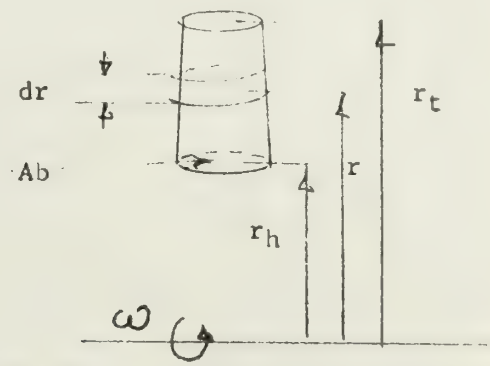


Figure 2-5. Rotating Turbine blade

$$dF = dmr\,\omega^2 = dmr\,(2\pi\Omega/60)^2 \tag{2.3-1}$$

$$A(r) = Ab\ f(r) \tag{2.3-2}$$

$$dm = Ab\ f(r)dr\,\frac{\rho}{go} \tag{2.3-3}$$

$$dF = (2\pi\Omega/60)^2\frac{\rho}{go}\,A(r)rdr$$

If $A(r)$ = constant

$$Fc = (2\pi\Omega/60)^2\frac{Ab\,\rho}{go}\int_{r_{hub}}^{r_{tip}} rdr \tag{2.3-4}$$

$$\delta c = \frac{Fc}{Ab} = (2\pi\Omega/60)^2\frac{\rho}{go}\left[\frac{r_{tip}^2 - r_{hub}^2}{2}\right]$$

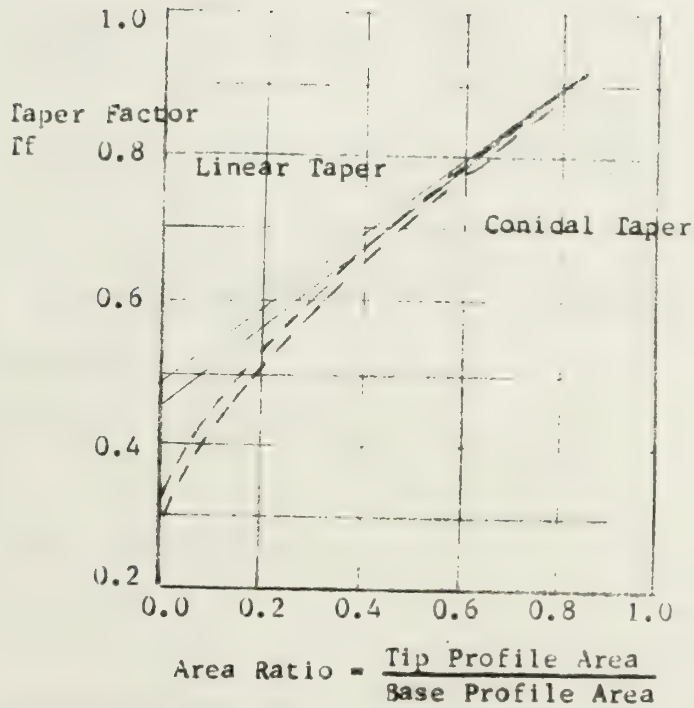


Figure 2-6. Variation of taper factor with blade profile area ratio (From Emmert, Current Design Practices for Gas Turbine Elements.(9))

$$\sigma_c = 4.51 \; Tf \, \rho \, Ab \left(\frac{\Omega}{1000}\right)^2 \qquad (2.3\text{-}5)$$

where; σ_c = average tensile stress(psi)

Tf = taper factor(from figure (2-6))

ρ_b = specific mass of the blade

A = annular flow area of blade ring (sq. in.)

Ω = shaft speed (rpm)

For the computer program Tf will be based on linear variation with tip to hub area ratio (areara) as an input, normally this will be between 0.25 - 0.333

If a linear taper is assumed equation (2.3-1) can be integrated directly assuming;

$$A(r) = Ab(1 - \alpha r) \qquad (2.3\text{-}6)$$

$$F_c = \left(\frac{2\pi\Omega}{60}\right)^2 \frac{\rho b}{go} Ab \int_{r_{hub}}^{r_{tip}} (1 - \alpha r) r dr \qquad (2.3\text{-}7)$$

$$= \left(\frac{2\pi\Omega}{60}\right)^2 \frac{\rho b}{go} Ab \left[\frac{(r_{tip}^2 - r_{hub}^2)}{2} + \frac{\alpha}{3}(r_{hub}^3 - r_{tip}^3)\right]$$

$$\sigma_c = \frac{F}{Ab} = \left(\frac{2\pi\Omega}{60}\right)^2 \frac{\rho b}{go} \left[\frac{(r_{tip}^2 - r_{hub}^2)}{2} + \frac{\alpha}{3}(r_{hub}^3 - r_{tip}^3)\right] \qquad (2.3\text{-}8)$$

and α can be evaluated

$$A_{tip} = \alpha \text{ area ratio } (Ab)$$

$$\alpha = \frac{1 - \text{area ratio}}{r_{tip}} \qquad (2.3\text{-}9)$$

2.3b Determination of ideal pitch to chord ratio. This value for P/C ratio is taken from figure (2-7) which is a correlation of Ainley's optimum spacing data. For stators the inlet gas angle to enter figure (2-7) is $-\alpha_1$ and the relative efflux angle is α_2. For rotors β_2 is the inlet gas angle while $-\beta_3$ is the relative efflux angle. This calculation is done in subroutine STOCRA and the input angles are taken at the mean radius.

2.3c Determination of non-dimensional section modulus(SM) and non-dimensional area at the base of the blade (Area/C^2). An input to get these values is the turning angle at the base of the blade. ie(hub for rotor and tip for stator). Figure (2-8) taken from reference(7) illustrates how the non dimensional base area is obtained. The non-dimensional section modulus is obtained from figure (2-9) which is

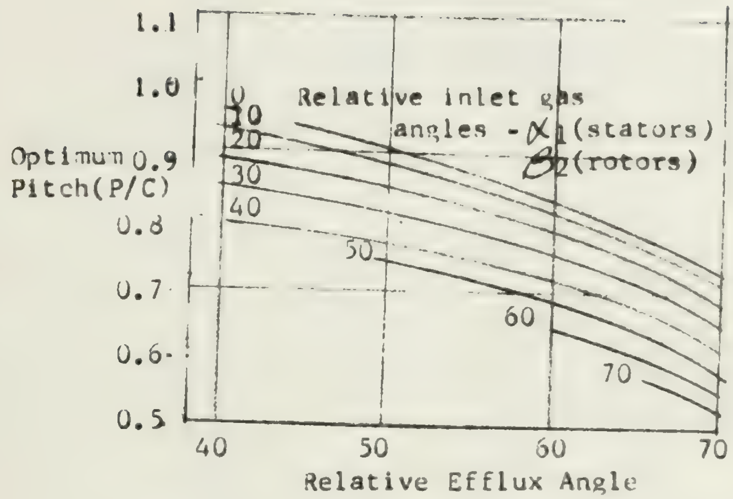


Figure 2-7. Optimum spacing of turbine blades. (From a correlation of Ainley's loss data (2))

an unpublished relationship provided by Ainley for use in reference (6). A modification was made to this relationship based upon calculations performed by Professor A.D. Carmichael to make the section modulus larger to conform to modern turbine blades. The SM was multiplied by 2.35 for use in the computer program.

2.3d Determining bending stresses on turbine blades. As can be seen in figure (2-10) and equation (2.3-10) a detailed calculation would be needed to determine the gas bending stresses on a turbine blade but because angle ϕ is small and Mw is by far the greater bending moment an approximation proposed in reference (6) is used in the preliminary design.

$$(\sigma_{gb})_{max} \approx \frac{\dot{m}\ Vx\ (\tan\alpha_2 - \tan\alpha_3)h}{2\ go\ n\ Z} \text{ (rotor)} \qquad (2.3\text{-}11)$$

Where the angles are taken at mean radius and the following are the definition of the parameters;

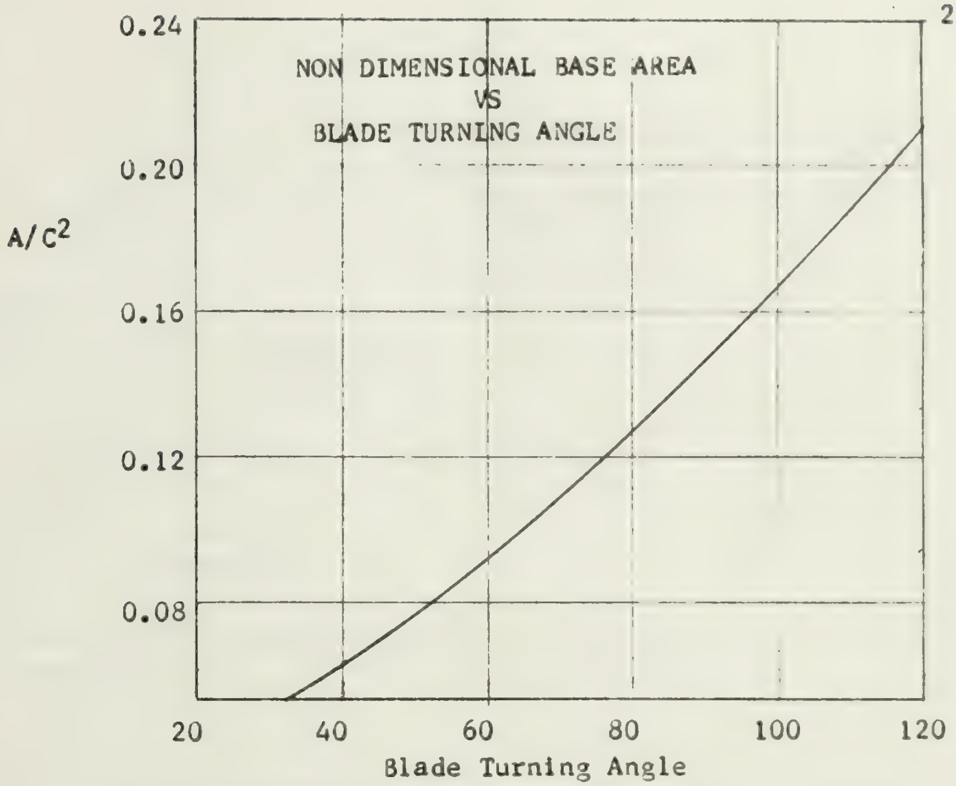


Figure 2-8. Approximate Areas of Turbine Blades vs Turning angle. (From paper by R.E.Dundas in Gas Turbine Handbook(7))

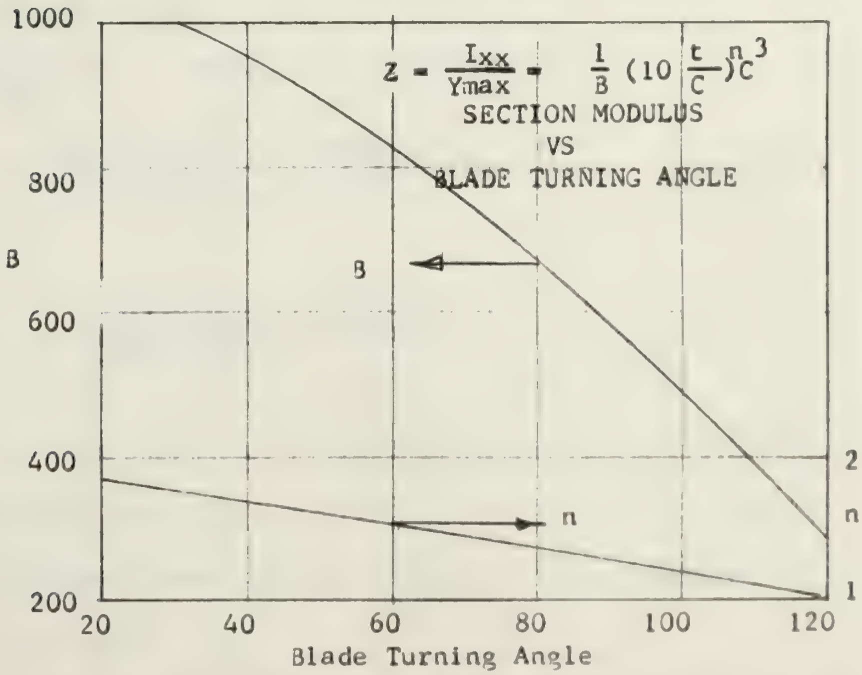
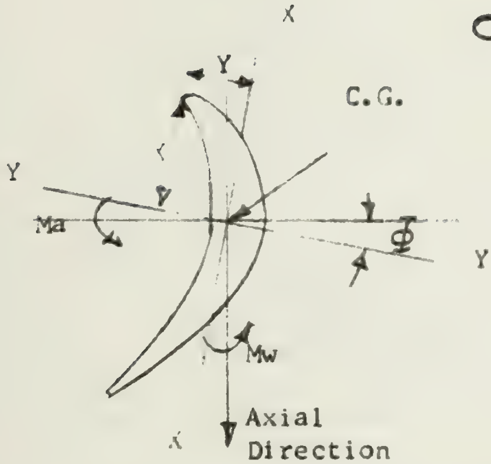


Figure 2-9. Section Modulus as a function of blade turning angle. (From unpublished paper by Ainley for use in reference (6))



$$\sigma_{gb} = \frac{X}{I_{yy}}(Ma\cos\Phi - Mw\sin\Phi) + \frac{Y}{I_{xx}}(Mw\cos\Phi + Ma\sin\Phi) \qquad (2.3\text{-}10)$$

Figure 2-10. Bending moments acting on a turbine blade.

Z = SM C Section Modulus

SM = non dimensional section modulus

n = number of blades

$$= \frac{2\pi r_m}{\text{Pitch}} \qquad \text{where } r_m = \text{mean radius}$$

$$(\sigma_{gb})_{max} = \frac{\dot{m}\, V_x\, (\tan\alpha_2 - \tan\alpha_3)\, h}{2\, g_o\, \frac{2\pi r_m}{P}\, SM\, C^3} \qquad (2.3\text{-}11a)$$

$$= \frac{\dot{m}\, V_x\, (\tan\alpha_2 - \tan\alpha_3)\, h}{4\pi g_o r_m\, SM\, C^2}\, \frac{P}{C}$$

At this point the blade chord has not been determined so the bending stress cannot be calculated, but equation (2.3-11a) will be coupled with a natural frequency equation and a cyclic loading equation to calculate the blade chord.

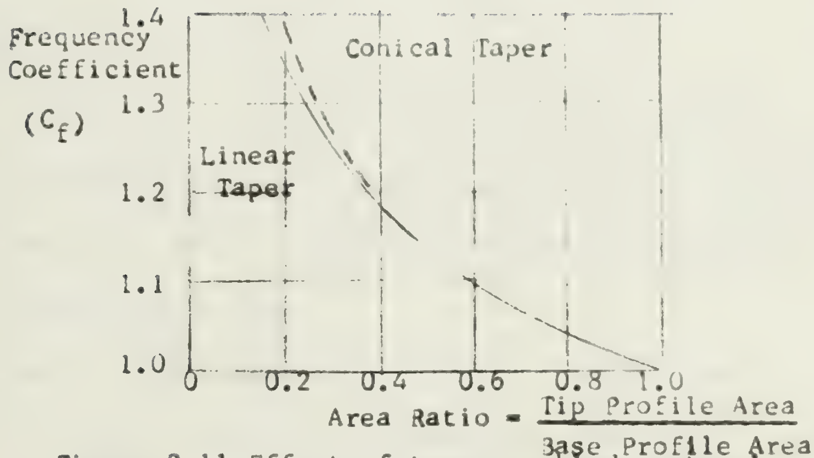


Figure 2-11 Effect of taper on blade natural frequency (From Emmert, Current Design Practices for Gas Turbine Power Elements (9))

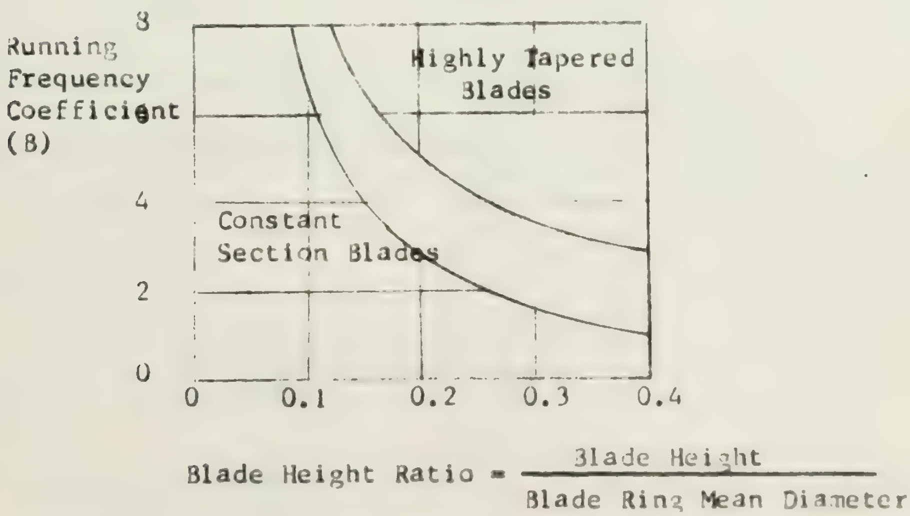


Figure 2-12. Variation of rotation coefficient with blade height ratio.(From Emmert, Current Design Practices for Gas Turbine Power Elements.(9))

2.3e Determination of natural bending frequency of blades from reference (9). The following expression is used in the computer program.

$$f_s = 11.0\ C_f \frac{k}{h^2}\sqrt{\frac{E}{\rho}} \qquad (2.3\text{-}12a)$$

f_s is standing frequency (cps)

C_f frequency correction factor taken from figure (2-11)

k minimum radius of gyration of base profile(in.)

h blade height (in)

E modulus of elasticity (psi) $(29 - 30) \times 10^6$ psi

ρb specific weight of blade material (lb/in^3)

$$f_s = 11.0 \frac{C_f}{h^2}\sqrt{\frac{IE}{A\rho}} \qquad (2.3\text{-}12b)$$

$$= 11.0 \frac{C_f}{h^2}\sqrt{\frac{ZtE}{A\rho}} \qquad \text{assuming } I \approx Zt$$

A cross sectional area of base of blade (in^2)

t maximum thickness of blade (in)

$= (t/C)\ C$

$A = (A/C^2)C^2$

$$f_s = 11.0 \frac{C_f}{h^2}\sqrt{\frac{SM\ C^3(t/C)E\ C}{(A/C^2)}}$$

$$= 11.0 \frac{C_f}{h^2}\left[\frac{SM(t/C)E}{(A/C^2)}\right]^{\frac{1}{2}} \text{chord} \qquad (2.3\text{-}12c)$$

The running frequency f given by equation (2.3-13) is a function of the natural frequency and the speed of rotation of the blade. The

factor B is given by figure (2-12). A plot of this frequency as a function of operating speed is illustrated in figure (2-13) which is called a Cambell Diagram. Normally for good design practice the running frequency should avoid the 1st four harmonics of the operating speed in its operating range. For the design of the blade chord in the computer program the effect of the rotational speed as indicated in equation (2.3-13) will be neglected but a more stringent criteria using the harmonics of the operating speed to estimate the vibrational stress in the blade will be used.

$$f_r = \sqrt{f_s^2 + B(\Omega/60)^2} \qquad (2.3\text{-}13)$$

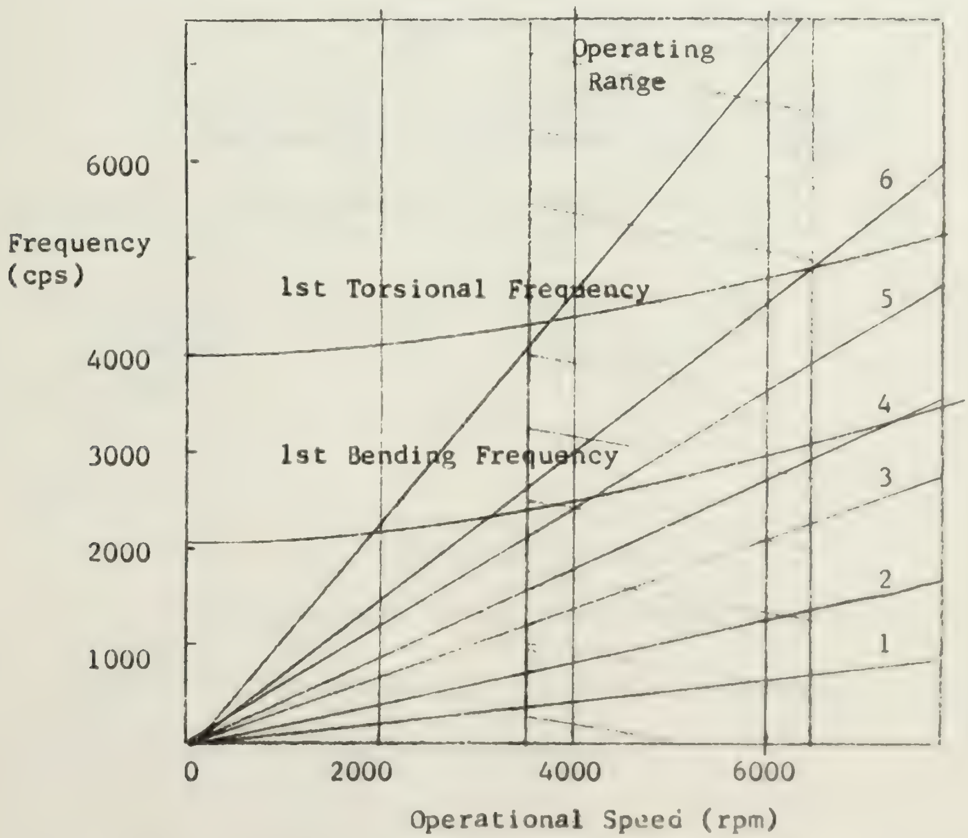


Figure 2-13. Cambell diagram, plot of frequency of vibrations as a function of operating speed.

2.3f **Determination of turbine blade characteristics based** on cyclic loading requirements by use of a Goodman Diagram of steady and vibrational stresses. In reference (7) a use of the Goodman diagram is used to determine the chord of a compressor blade. This can also be applied to turbine blades. A Goodman diagram is a plot of vibrational stresses as a function of steady stresses. The vibrational stress is taken at 10^7 cycles at the operating temperature.

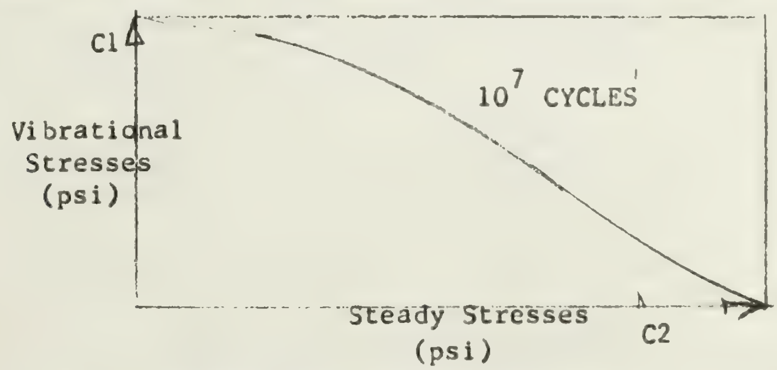


Figure 2-14. Goodman Diagram of Vibrational stresses as a function of steady stresses.

This plot can be approximated as a linear function.

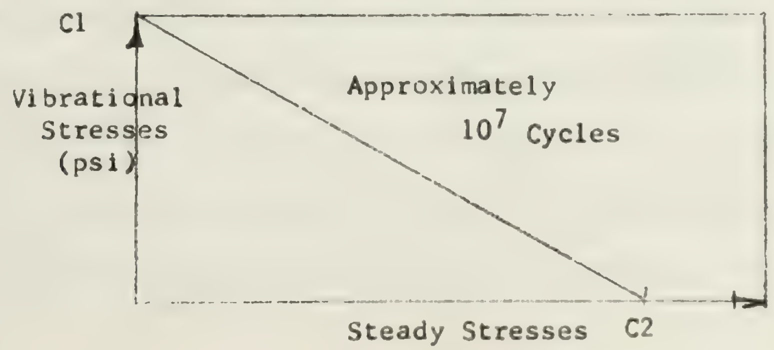


Figure 2-15. Linearlized Goodman Diagram

In reference (7) the vibrational stress is proposed as a function of the bending stress as shown in equation (2.3-14)

$$\sigma vib = 1.3 \text{ Amplification factor } \sigma gb \qquad (2.3\text{-}14)$$

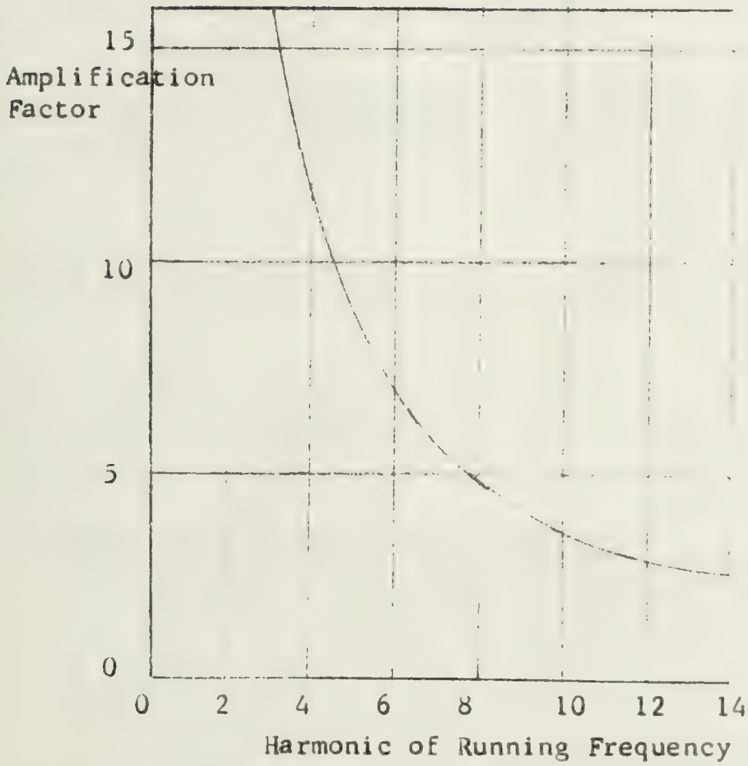


Figure 2-16. Amplification Factor. (From Paper of Trumpler & Owens (19))

where Amplification factor is shown in figure (2-16) as a function of the harmonic of operating speed. The 1.3 is a stress concentration factor specified in reference (7). From personal conversation with Professor A. Douglas Carmichael at M.I.T. the amplification factor can be approximated by 41/n where n is the harmonic of the operating speed.

$$n = \frac{f}{\left(\frac{\Omega (rpm)}{60}\right)} = \left(\frac{f}{\Omega}\right) 60 \qquad (2.3\text{-}15)$$

From figure (2-15)

$$\sigma_{vib} = C1 - \frac{C1}{C2}\sigma_{steady} \qquad (2.3\text{-}16)$$

where $\sigma_{steady} = \sigma_{centrifugal} + \sigma_{gas\ bending}$

and C1 is the upper limit for vibrational stresses and C2 is the

upper limit for steady stresses.

$$\sigma_{gb}\,\frac{1.3\,\Omega/60}{f} + \frac{C1}{C2} = C1 - \frac{C1}{C2}\left(\sigma_{cf}\right)$$

$$\text{but } \frac{C1}{C2} \ll \frac{1.3\,(\Omega/60)41}{f}$$

$$\text{so } \sigma_{gb}\frac{(1.3\times 41\times \Omega/60)}{f} \approx C1 - \frac{C1}{C2}\left(\sigma_{cf}\right) \qquad (2.3\text{-}17)$$

From equation (2.3-11a), (2.3-12c), and (2.3-17)

$$\frac{\dot{m}Vx(\tan\alpha 2 - \tan\alpha 3)}{4\pi g_o\ r_m\ SM\ C^3}\left(\frac{P}{C}\right)\frac{h(1.3\times 41\times(\Omega/60))}{\frac{11.0\times C_f}{h^2}\left[\frac{SM(t/C)E}{(A/C^2)\rho}\right]^{\frac{1}{2}}} = C1 - \frac{C1}{C2}\sigma_{cf}$$

(2.3-18)

$$\text{Stress}3 = \frac{\dot{m}Vx(\tan\alpha 2 - \tan\alpha 3)h}{4\pi g_o\ r_m SM}\left(\frac{P}{C}\right) \qquad (2.3\text{-}19)$$

$$\text{Freq} = \frac{11.0\times C_f}{h^2}\left[\frac{SM(t/C)}{(A/C^2)\rho}\right]^{\frac{1}{2}} \qquad (2.3\text{-}20)$$

$$\frac{1.3\times 41(\Omega/60)}{C^3\ \text{Freq}}\ (\text{Stress}3) = C1\left(1 - \frac{\sigma_{cf}}{C2}\right) \qquad (2.3\text{-}18a)$$

$$C4 = 1.3\times 41(\Omega/60)\ \text{Stress}3/\text{Freq} \qquad (2.3\text{-}21)$$

$$\frac{C4}{C^3} = C1\left(1 - \frac{\sigma_{cf}}{C2}\right)$$

$$\text{Chord} = C = \left[\frac{C4}{C1\left(1 - \frac{\sigma_{cf}}{C2}\right)}\right]^{1/3} \qquad (2.3\text{-}22)$$

Now that the chord has been determined the bending stress and natural bending frequency can be determined from equation (2.3-11a) and (2.3-12c) respectively. Having solved for the chord at the base of the blade the chord can be determined at mean and tip assuming a linear taper.

$$Abm = \frac{Ab(1 + Areara)}{2} \tag{2.3-23}$$

Assuming constant (A/C^2)

$$Cm = \left[\frac{Abm}{(A/C^2)}\right]^{\frac{1}{2}} \tag{2.3-24}$$

At the opposite end from the base

$$C_t = \left[\frac{Arearatio(Ab)}{(A/C^2)}\right]^{\frac{1}{2}} \tag{2.3-25}$$

where $C_t = C_{hub}$ (for stator)

$C_t = C_{tip}$ (for rotor)

Now that the chord has been determined at the midchord the aspect ratio and pitch can be determined by equation (2.3-26) and (2.3-27).

$$\text{Aspect ratio } (h/C) = h/Cm \tag{2.3-26}$$

$$Pitch_m = (P/C)\ Cm \tag{2.3-27}$$

With pitch determined the number of blades can be calculated.

$$\text{Number of blades (N)} = \text{Integer}\left[\frac{2\pi r_m}{Pitch}\right] \tag{2.3-28}$$

The computer program uses the criteria of having even number of blades for the stator and prime numbers for the rotor to prevent blade interaction of resonant frequencies. The determination of whether a number is prime is done in subroutine TESTP. Thus having solved for the number of blades the pitch can be recalculated and the weight

of the blades. Blades are integrated from the base to end to get volume and is multiply by its specfic weight to get the total weight. In the computer program this specific weight is used for both the blades and disc. Also it is assumed they are solid blades with no cooling passages.

$$\text{Weight of blades} = N\rho b \int_{r_h}^{r_t} A(r)dr \qquad (2.3\text{-}29)$$

$$= N\rho b A b \int_{r}^{r_t} (1 - \alpha r)dr$$

$$= N\rho b A b \left[(r_t - r_h) + \frac{\alpha}{2}(r_h^2 - r_t^2) \right]$$

where α is given by equation (2.3-9)

In this section pitch was determined by a chart of ideal pitch to reduce losses. In actual turbine design the loss data would be coupled with stress analysis of the turbine blade attachment to determine allowable pitch. The type most commonly used is the fir-tree method which is illustrated in figure (2-17). This method of selecting turbine blade chord length is just one of many which are used in industry.

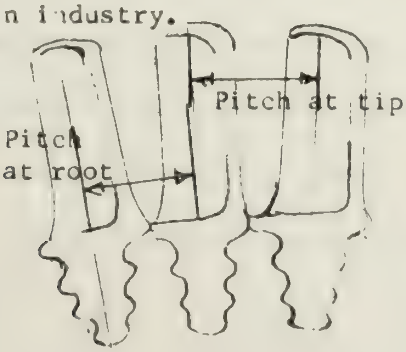


Figure 2-17. Firtree blade attachments.

2.4 Turbine Disc Design

The method for design of a disc in this section will be based upon a constant average stress analysis. The stress relations are those proposed in reference (15) and (18). This method will ignore stress concentrations and thermal stresses. In actual dis. design these cannot be ignored since thermal stresses may be a major part of the disc stresses and stress concentrations may cause the disk to fail even though the average stress is well below the ultimate tensile stress of the material (UTS). For calculations in the computer program the average tensile stress used is that shown in equation (2.4-1) from reference (7).

$$\sigma_{avg} = \frac{0.75\ UTS}{\left[\frac{Nb}{No}\right]^2} \qquad (2.4\text{-}1)$$

$$\left[\frac{Nb}{No}\right] = \text{Ratio of burst speed to design speed} \qquad (2.4\text{-}2)$$

The value of this ratio is normally between 1.2 - 1.3. The value of ultimate tensile stress (UTS) is taken at the design operating temperature, higher values producing smaller disc dimensions. This value is an input to the computer program. The computer program has minimum values for some of the dimensions illustrated in figure (2-18) to prevent impossibilities to manufacture and to allow adequate thickness for attachment of blades

The following equations are based on figure (2-18) taken from reference (1?).

$$\sigma_{avg} = \frac{\rho\omega^2 r_o^2 + \frac{N}{2\pi}\sigma_b \frac{Ab}{WoTo}}{1 + \frac{Zor_o}{WoTo}} \qquad (2.4\text{-}3)$$

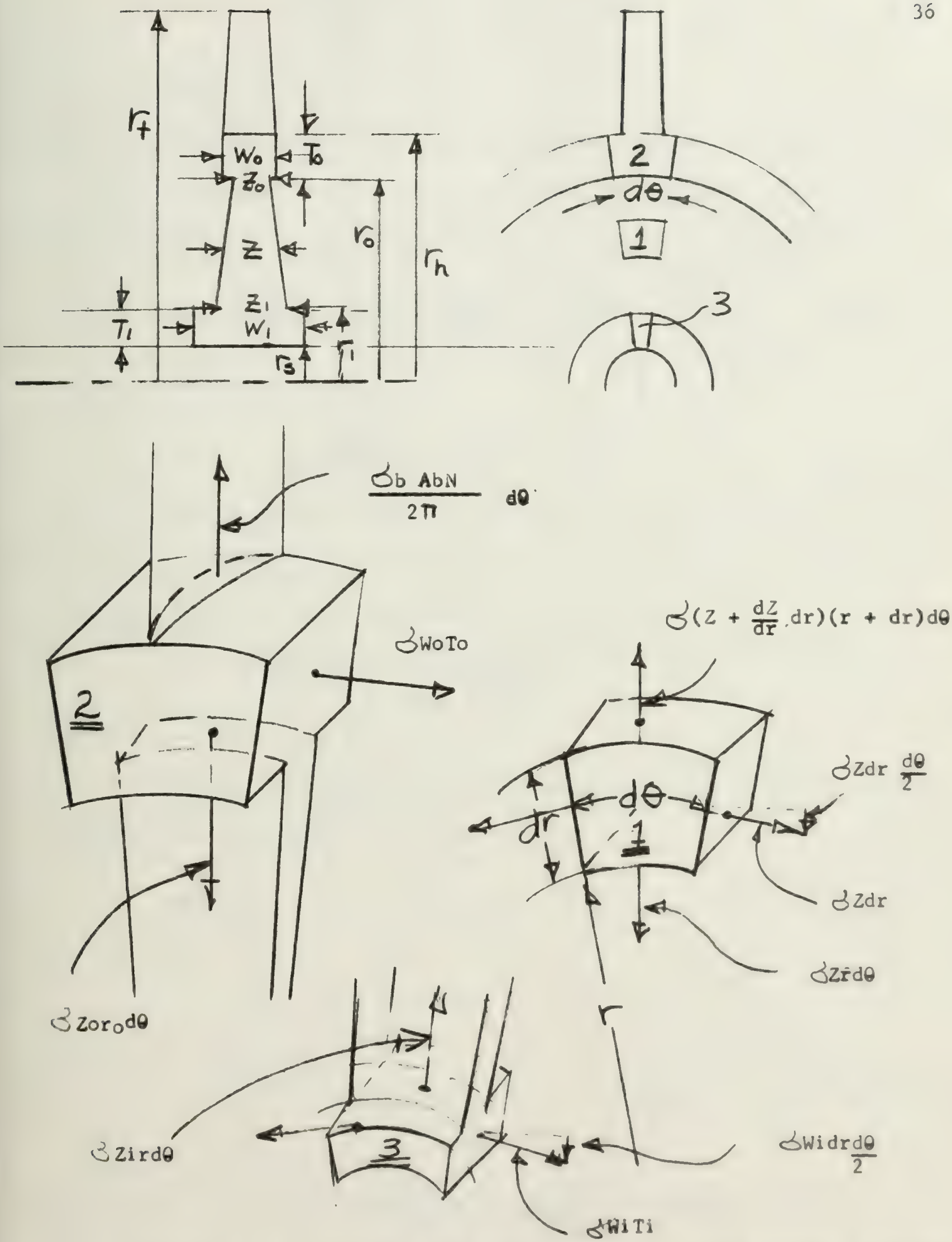


Figure 2-18. Turbine disc stress analysis (From Aircraft Turbines by J.L.Kerrebrock(15))

$$\sigma_b = \frac{\rho\omega^2 r_t^2}{2go}\left\{1 - \left(\frac{r_h}{r_t}\right)^2 - \frac{2\alpha r_t}{3}\left[1 - \left(\frac{r_h}{r_t}\right)^3\right]\right\} \qquad (2.4\text{-}4)$$

for a linear tapered blade.

For the computer program Wo will be assumed to equal .65 chord and To will equal half of Wo unless otherwise specified. With these parameters known Zo can be solved for by equation (2.4-5). With Zo

$$Zo = \left(\frac{WoTo}{r_o}\right)\left\{\left[\left(\frac{r_o}{r_t}\right)^2 + \frac{N\sigma_b}{2\pi WoTo}\right]\frac{\rho\omega^2 r_t^2}{2\sigma go} - 1\right\} \qquad (2.4\text{-}5)$$

known Z(r) can be solved for.

$$Z(r) = Zo\, e^{\frac{\rho\omega^2 r_t^2}{\sigma 2go}\left[\left(\frac{r_o}{rt}\right)^2 - \left(\frac{r}{rt}\right)^2\right]} \qquad (2.4\text{-}6)$$

with a minimum of 0.3 inches. The value of r_i is assumed to equal 2 r_{shaft} where r_{shaft} is an input to the computer program. This defines Ti so Wi can be solve for in equation (2.4-7).

$$Wi = \left(\frac{Zir_i}{Ti}\right)\left[1 - \left(\frac{r_i}{r_t}\right)^2\frac{\rho\omega^2 r_t^2}{go\sigma}\right] \qquad (2.4\text{-}7)$$

with a minimum of 1.2 Wo.

Having determined the dimensions of the disc the weight of the disc can be determined by equation (2.4-8)

$$\text{Disc weight} = \rho\int_0^{2\pi}\int_{r_s}^{r_o} A(r)\,dr\,d\theta \qquad (2.4\text{-}8)$$

$$= \rho 2\pi\int A(r)\,dr$$

$$= 2\pi\rho\left[Wi\int_{r_{shaft}}^{r_i} r\,dr + \int_{r_i}^{r_o} Z(r)\,r\,dr + Wo\int_{r_o}^{r_h} r\,dr\right]$$

$$= 2\pi\rho\left\{\frac{Wi}{2}(r_i^2 - r_{shaft}^2) + \frac{Wo}{2}(r_h^2 - r_o^2)\right.$$

$$\left. + 2Zor_t^2\, e^{\frac{\rho\omega^2 r_o^2}{2\sigma go}}\left[e^{-\frac{\rho\omega^2 r_t^2}{2\sigma go}\left(\frac{ri}{rt}\right)^2} - e^{-\frac{\rho\omega^2 rt^2}{2\sigma go}\left(\frac{ro}{rt}\right)^2}\right]\right\}$$

Having determined the dimensions of the disc, the burst speed can be computed assuming the disc yields prior to bursting. For this analysis the disc is divided in half as illustrated in figure (2-19) and the stress is assumed constant over area 2A. The force acting on this area is composed of the disc load and the blade load. It is assumed that the blade load is evenly distributed on the outer rim. In actual stress analysis of the disc this assumption is an over simplification of the stress, but for preliminary design purposes it will be adequate. A more detailed analysis is covered in reference (7). The force due to the disc is now calculated by taking the force in the direction perpendicular to the area 2A caused by the disc load and summing it over the disc half and adding this to the force caused by the blade load. This force is divided by the area 2A to get the average tensile stress σ_{ta}. This stress is set equal to the ultimate tensile strength of the material of the disc at its operating temperature. The value of Nb is then calculated by equation (2.4-16)

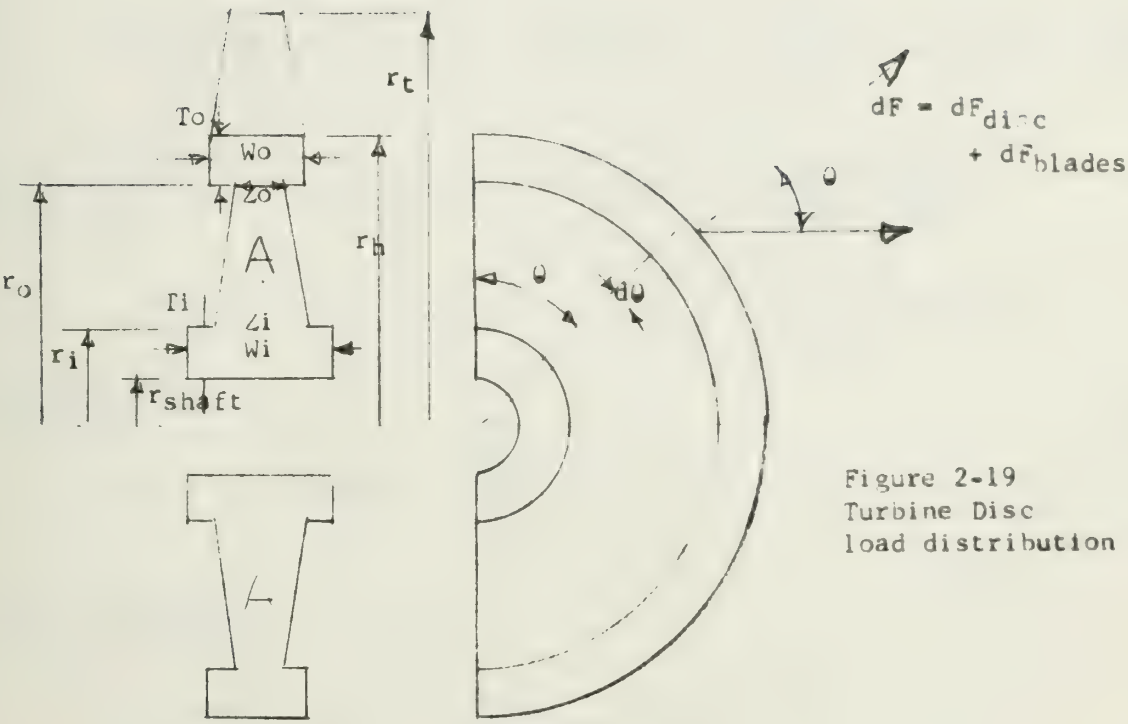


Figure 2-19
Turbine Disc
load distribution

Total area = 2A

$$A = W_i T_i + \int_{r_i}^{r_o} Z(r)\,dr + W_o T_o \tag{2.4-9}$$

<u>For disc load</u>

$$dm = \frac{\rho}{g_0} dV \tag{2.4-10}$$

$$dF = (dm\, r\omega^2)\sin\theta = dm\, r\left(\frac{2\pi\Omega}{60}\right)^2 \sin\theta \tag{2.4-11}$$

$$F = \left(\frac{2\pi N_b}{60}\right)^2 \frac{\rho}{g_0} \int_0^{\pi}\int_{r_{shaft}}^{r_h} Z(r)\, r^2 \sin\theta\, d\theta\, dr \tag{2.4-12}$$

$$= \left(\frac{2\pi N_b}{60}\right)^2 \frac{\rho}{g_0}\, 2\int_{r_{shaft}}^{r_h} Z(r)\, r^2\, dr$$

$$F = \left(\frac{2\pi Nb}{60}\right)^2 \frac{\rho}{go}\, 2 \left[Wi \int_{r_{shaft}}^{r_i} r^2 dr + \int_{r_i}^{r_o} Z(r) r^2 dr + Wo \int_{r_o}^{r_h} r^2 dr \right]$$

$$= \left(\frac{2\pi Nb}{60}\right)^2 \frac{\rho}{go}\, 2 \left[\frac{Wi(r_i^3 - r_{shaft}^3)}{3} + Zo\, C \int_{r_i}^{r_o} e^{-ar^2} r^2 dr + \frac{Wo(r_h^3 - r_o^3)}{3} \right]$$

$Zo\, e^{\frac{\rho\omega^2 r_t^2}{2\sigma go}} \int_{r_i}^{r_o} e^{-ar^2} r^2 dr$ is integrated numerically $\quad a = \frac{\rho\omega_b^2 r_t^2}{\sigma_{avg}\, 2go} \left[\left(\frac{1}{r_t}\right)^2\right]$

$$\sigma ta(\text{due to disc}) = \frac{F_{disc}}{2A} \qquad (2.4\text{-}13)$$

For blade load

$$\sigma ta(\text{due to blades}) = \frac{N\sigma b(Ab)}{2\pi A} \qquad \sigma b \text{ given by equation(2.4-4)}$$

(2.4-14)

Average disc stress

$$\sigma ta(\text{Disc + blades}) = \frac{F_{disc} + F_{blades}}{2A} \qquad (2.4\text{-}15)$$

Set σta = ULT (ultimate tensile strength of material)

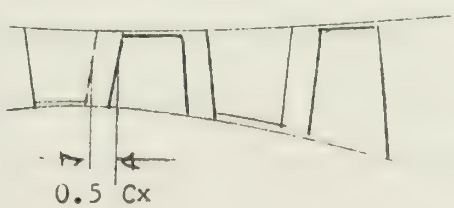
The burst speed Nb can now be calculated. This value will slightly higher than that in equation (2.4-2) due to approximations and arbitrary values selected for some of the disc dimensions.

$$Nb = \left(\frac{30}{\pi}\right) \left[\frac{go}{\rho} \frac{\sigma_{ult}\, 2A}{2 \int_{r_{shaft}}^{r_h} Z(r) r^2 dr + \frac{NAbr}{2\pi}\left(1 - \left(\frac{r_h}{r_t}\right)^2 - \frac{\alpha r_t}{3}\left[1 - \left(\frac{r_h}{r_t}\right)^3\right]\right)} \right]^{\frac{1}{2}}$$

(2.4-16)

2.5 Having determined the blade and disc dimensions the axial length of the turbine can be calculated. To do this a criteria for spacing between blades must be selected. From reference (6) the values of spacing between blades is 0.2 to 0.5 of the axial chord length. The longer dimension will tend to reduce the flare which would prevent the gas flow to separate from the turbine wall. It would also decrease the chance of inducing vibrational stresses. The shorter dimension would decrease the size and weight of the turbine. For the computer program a value of ½ the average axial chord at mid-height was selected. The computer program will then calculate the axial length and weight of the shaft from station 1 of the 1st stage to station 3 of the last stage. A value of 18^{o} was selected as the stagger angle in the computer program.

Figure 2-20 Axial Spacing between blades



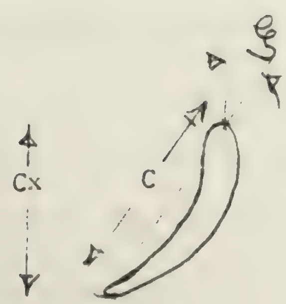


Figure 2-21 Stagger Angle of Turbine blades

Chapter 3

Performance Estimation

3.1 The design and off-design characteristics are very important in a complete analysis of a gas turbine since most turbines do not operate only at their design point. Also cycle calculations without actual loss data can not accurately determine the efficiency of a turbine, so this analysis can give a more accurate assessment of the efficiency that can be achieved in the turbine.

The Ainley-Mathieson Method for performance estimation was selected over other methods because it seems to have a wider application and can be easily used for off-design performance calculations. The modifications proposed in reference (8) have been applied. These modifications can reduce the error from $\pm 3\%$ to $\pm 2\%$ for most turbines and are based on modern turbines while the data by Ainley and Mathieson were accumulated over 20 years ago on turbines that existed at that time. The calculation procedure for off-design performance is that proposed by Horlock in reference (12). A description of the Improved Ainley Mathieson Performance Estimation Method will be presented first followed by a description of off-design calculations which use loss coefficients to determine gas properties, isentropic efficiency and static efficiency at design and off-design points.

The computer program used pressure loss coefficient $Y = (Po1 - Po2) / (Po2 - P_2)$ for the performance analysis. This coefficient is a function of aspect ratio (H/C), pitch to chord ratio (P/C), velocity, Mach number, trailing edge thickness, thickness to chord ratio (t/C), incidence angle, tip clearance, Reynolds number, etc. This coefficient

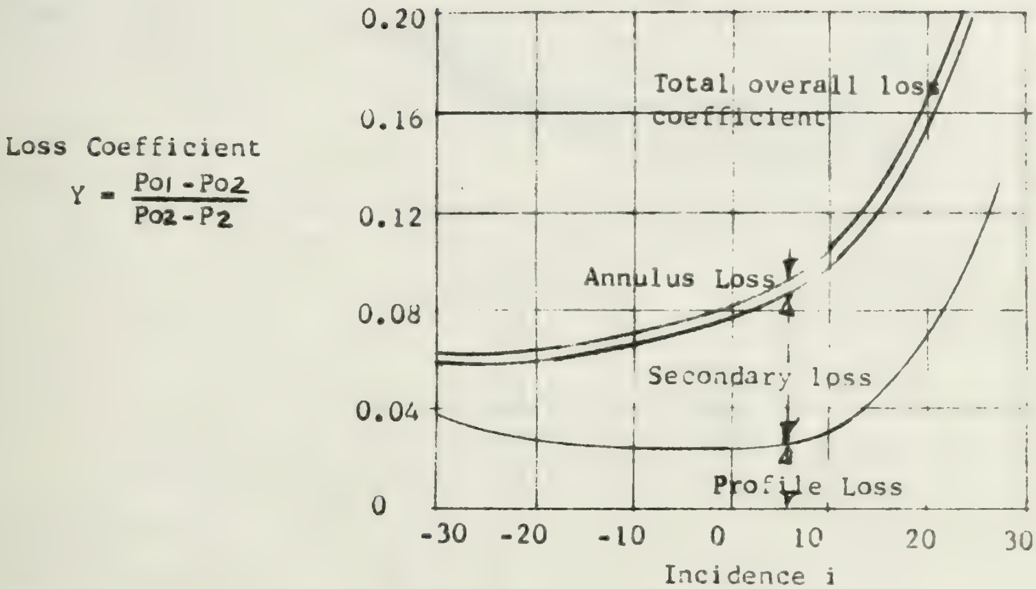


Figure 3-1. Analysis of losses in flow through a row of turbine blades(From D.G.Ainley and G.C.R.Mathieson(1))

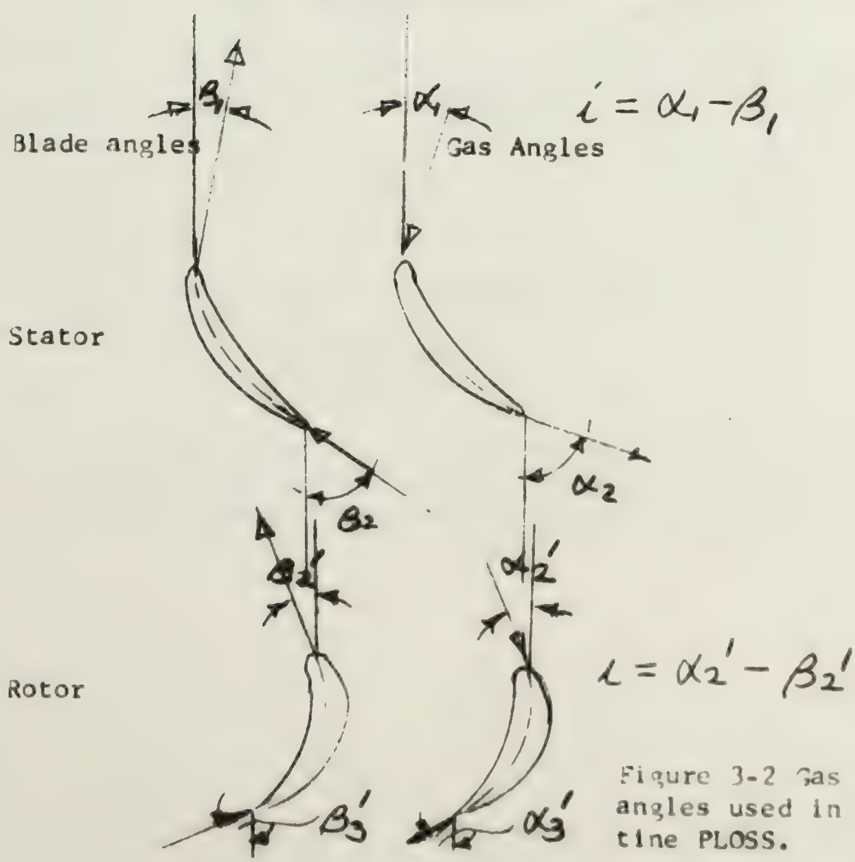


Figure 3-2 Gas and blade angles used in subroutine PLOSS.

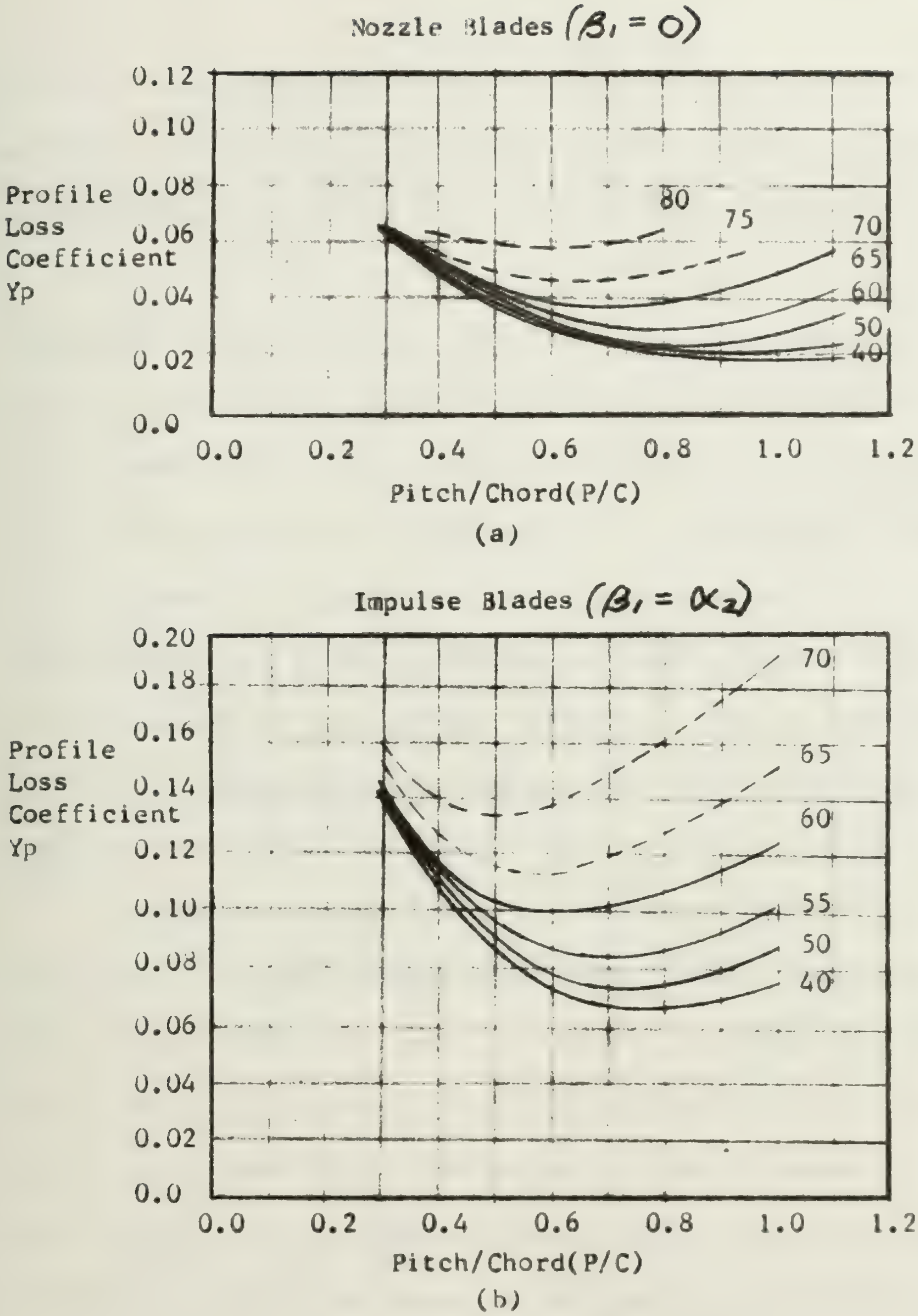


Figure 3-3. Profile-loss coefficients for conventional section blades at zero incidence. t/c = 20 per cent; Re = 2×10^5; M 0.6 From D.G.Ainley and G.C.R.Mathieson(2))

is broken down into three parts, Yp (profile loss), Ys (secondary loss), and Yk (clearance loss). Figure (3-1) from reference (1) shows the first two, Yp and Ys in which the annulus loss is grouped into secondary losses. The modification of the Ainley-Mathieson method mostly affects the secondary and tip clearance loss coefficients, but has an affect on profile loss Yp for Mach numbers greater than 1, and a Reynolds number correction to the profile and secondary loss coefficients.

3.2 The pressure loss coefficient Y is calculated in subroutine PLOSS. Figure (3-2) shows the sign convention used in this subroutine, where β angles are blade angles and α angles are gas angles. The angles as shown are in the positive direction. The (') implies relative angles. <u>This sign convention and notation applies only to subroutine PLOSS</u> in order to have a standard form for stator and rotor.

Figure (3-3a) and 3-3b) coupled with equation (3.2-1) is used to calculate the profile loss coefficient Yp for 0 incidence, where $\beta_1 = 0$ values come from figure (3-3a) and $\beta_1 = \alpha_2$ comes from figure (3-3b). The pitch to chord ratio (P/C) is the argument for entering figures (3-3a) and(3-3b). The correction for thickness to chord ratio (t/C) is done in equation (3.2-1) along with the correction for the ratio of inlet blade angle to exit gas angle (β_1/α_2). The value obtained is Yp for zero incidence (i=0).

For off-incidence calculations figures (3-4) a,b,c, and figure (3-5) are used. Figure (3-4) a,b,c determine the stalling incidence so that figure (3-5) can then be used to correct Yp for off-incidence cases.

$$Yp = \left\{ Yp(\beta_1=0) + (\beta_1/\alpha_2)^2 \left[Yp(\beta_1=\alpha_2) - Yp(\beta_1=0) \right] \right\} \left[\frac{t/C}{0.2} \right]^{(\beta_1/\alpha_2)} \quad (3.2\text{-}1)$$

$$\alpha_2(P/C=.75) = \frac{\alpha_2}{(\alpha_2/(\alpha_2(P/C=.75))} \quad (3.2\text{-}2)$$

Figure (3-4b) is entered with the argument of pitch to chord ratio (P/C) . The ratio of exit gas angle α_2 to exit angle $\alpha_2(P/C=.75)$ is then determined. It is now possible to determine $\alpha_2(P/C=.75)$. Having determined $\alpha_2(P/C=.75)$, figure (3-4c) is now entered with $\alpha_2(P/C=.75)$ to get the stalling incidence $i_s(P/C=.75)$. Figure (3-4a) is now entered with exit gas angle α_2 and P/C to get $\Delta i_s = i_s - i_s(P/C=.75)$. i_s can then be solved for. Having incidence angle i and i_s the ratio (i/i_s) for entering figure (3-5) to determine ratio Yp/Yp(i=0) is known. Having previously solved for Yp(i=0) in equation (3.2-1) Yp is now known for off incidence.

$$Ys = .0334(C/H)(\cos^2\alpha_2/\cos^3\alpha_m)Z \quad (3.2\text{-}3)$$

For secondary losses Ys is computed by equation (3.2-3) from reference (8). Where Z is the Ainley loading parameter from reference (2).

$$Z = \left[\frac{C}{P/C} \right] \frac{\cos^2\alpha_2}{\cos^3\alpha_m} \quad (3.2\text{-}4)$$

$$\alpha_m = (\alpha_1 - \alpha_2)/2 \qquad \text{(for stator)} \qquad (3.2\text{-}5a)$$

$$\alpha_m = (\alpha_3' - \alpha_2')/2 \qquad \text{(for rotor)} \qquad (3.2\text{-}5b)$$

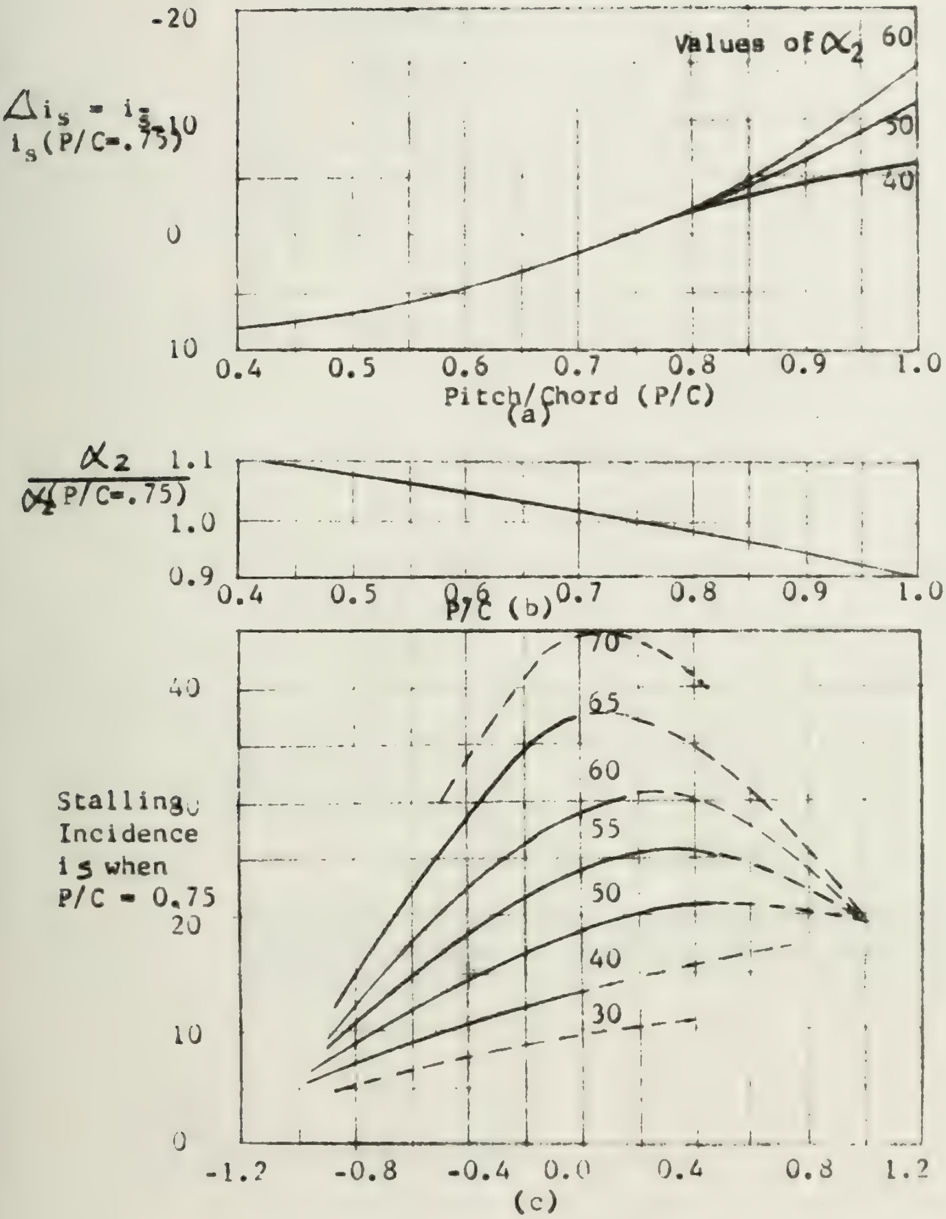


Figure 3-4. Off-design performance of cascades of turbine blades. Re = 2×10^5. (a) variation of stalling incidence with pitch-chord ratio; (b) variation of α_2 with p/c; (c) stalling incidence of turbine blade sections when p/c = 0.75. (From D.G. Ainley and G.C.R. Mathieson(2))

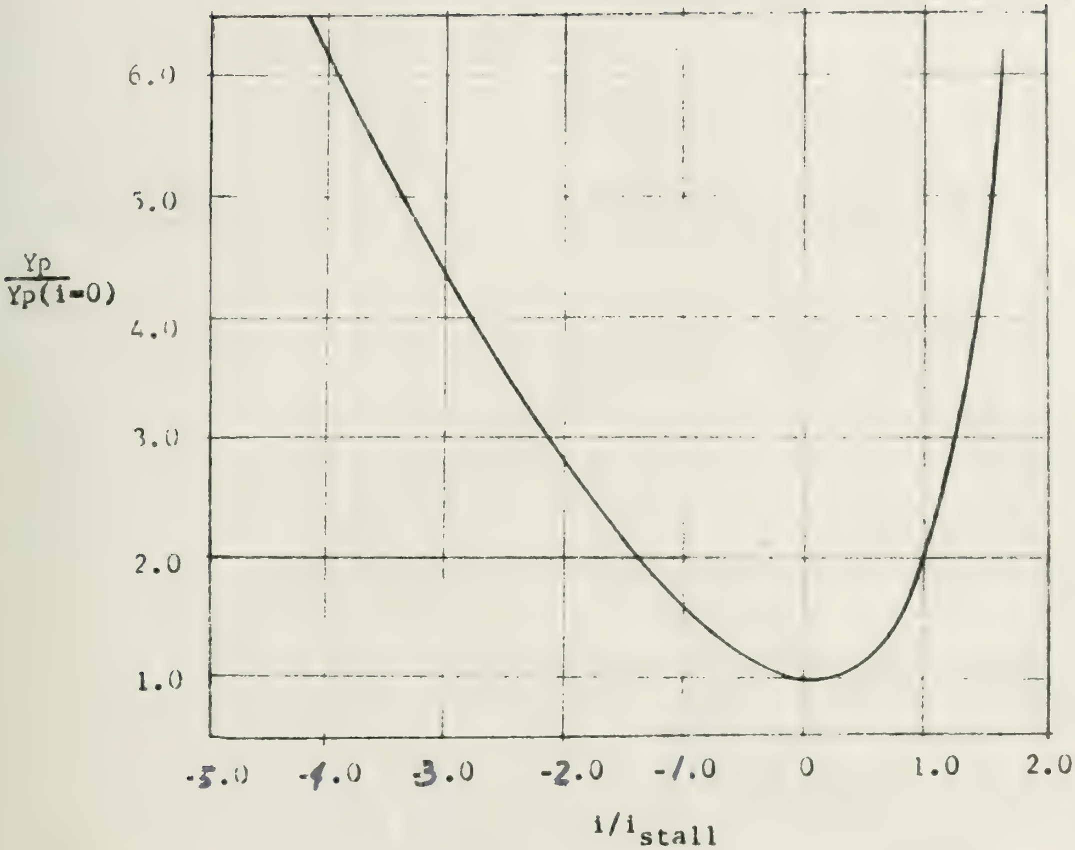


Figure 3-5. Variation of relative profile loss with relative incidence. (From D.G.Ainley and G.C.R. Mathieson(2))

$$\left[\frac{C_L}{P/C}\right] = 2(\tan\alpha_1 + \tan\alpha_2) \qquad (3.2\text{-}6a)$$

$$\left[\frac{C_L}{P/C}\right] = 2(\tan\alpha_2' + \tan\alpha_3') \qquad (3.2\text{-}6b)$$

For tip clearance losses Yk is computed by equation (3.2-7) from reference (3).

$$Yk = B(C/H)(k/C)^{.78} \qquad (3.2\text{-}7)$$

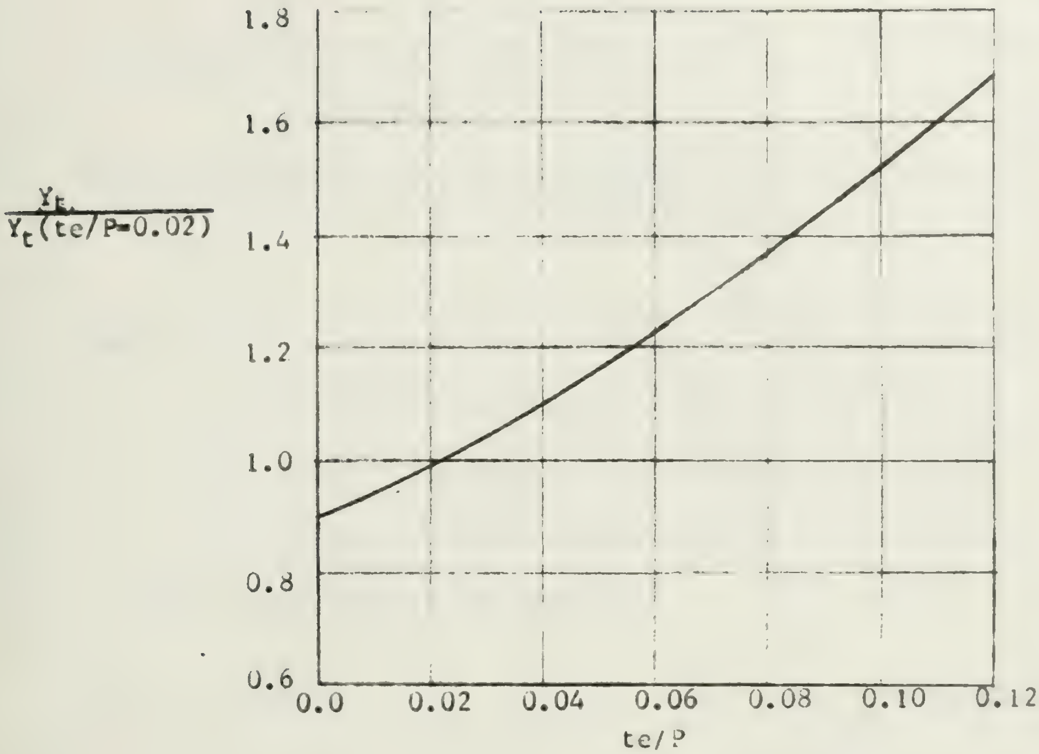


Figure 3-6. Effect of trailing edge thickness on blade coefficients. (From D.G.Ainley and G.C.R.Mathieson(2))

For equation (3.2-7)

$B = .37$ for shrouded blades

$B = .47$ for plain tip clearance

$B = .00$ for stator blades

k = tip clearance

C = chord

H = blade height

Having determined Y_p and Y_s they can be corrected for Mach number and Reynold's number from equation (3.2-8) and (3.2-9) respectively.

$$(Yp)\ \text{corrected} = Yp(1+60(Mn-1)^2) \qquad (3.2\text{-}8)$$

for $Mn > 1$

$$(Yp + Ys)\ \text{corrected} = (Yp + Ys)\left[\frac{Re}{2\times 10^5}\right]^{-.2} \qquad (3.2\text{-}9)$$

Now the total loss coefficient Yt can be computed by equation (3.2-10). This coefficient is now corrected for thickness of trailing edge to pitch ratio (te/P) from figure (3-6) to get the total loss coefficient for the blade row. Illustrations of an example calculation can be found in reference (2) and (12).

$$Yt = Yp + Ys + Yk \qquad (3.2\text{-}10)$$

3.3 In this section it will be explained how the loss coefficient Yt solved for in section 3.2 is coupled with compressible flow tables to estimate performance. The method explained is that outlined in reference (12). Another method is explained in reference (2). Calculations will be carried out only at the mean radius which should give a fairly accurate assessment of the turbine performance.

The calculations are started at the inlet of the turbine and worked through each stage where the exit conditions at one blade row is the inlet to the next blade row until the turbine exit of the last stage is reached.

For inlet conditions the values for Toi and Poi will remain constant, the mass flow and corrected speed $\left(N/\sqrt{Toi}\right)/(N/\sqrt{Toi})dp$ will will be varied. This will allow the values of efficiency verses pressure ratio and $\left(\frac{\dot{m}\sqrt{Toi}}{Poi}\right)\Big/\left(\frac{\dot{m}\sqrt{Toi}}{Poi}\right)_{dp}$ verses pressure ratio to be calculated as illustrated in Figure (3-7).

3.3a Flow through the nozzle.

(1) Select the mass flow.

(2) Assume an exit Mach number.

(3) With known blade angles subroutine STOCRA is entered as in section (2.2) only this time the blade angles will be used to determine the exit gas angles.

(4) From compressible flow tables for the assumed Mach number the values of $(P_2/Po2)$ and $(V_2/\sqrt{To2})$ are determined, which will then determine V_2 and T_2

$$V_2 = \sqrt{To2}\,(V_2/\sqrt{To2}) \qquad (3.3\text{-}1)$$

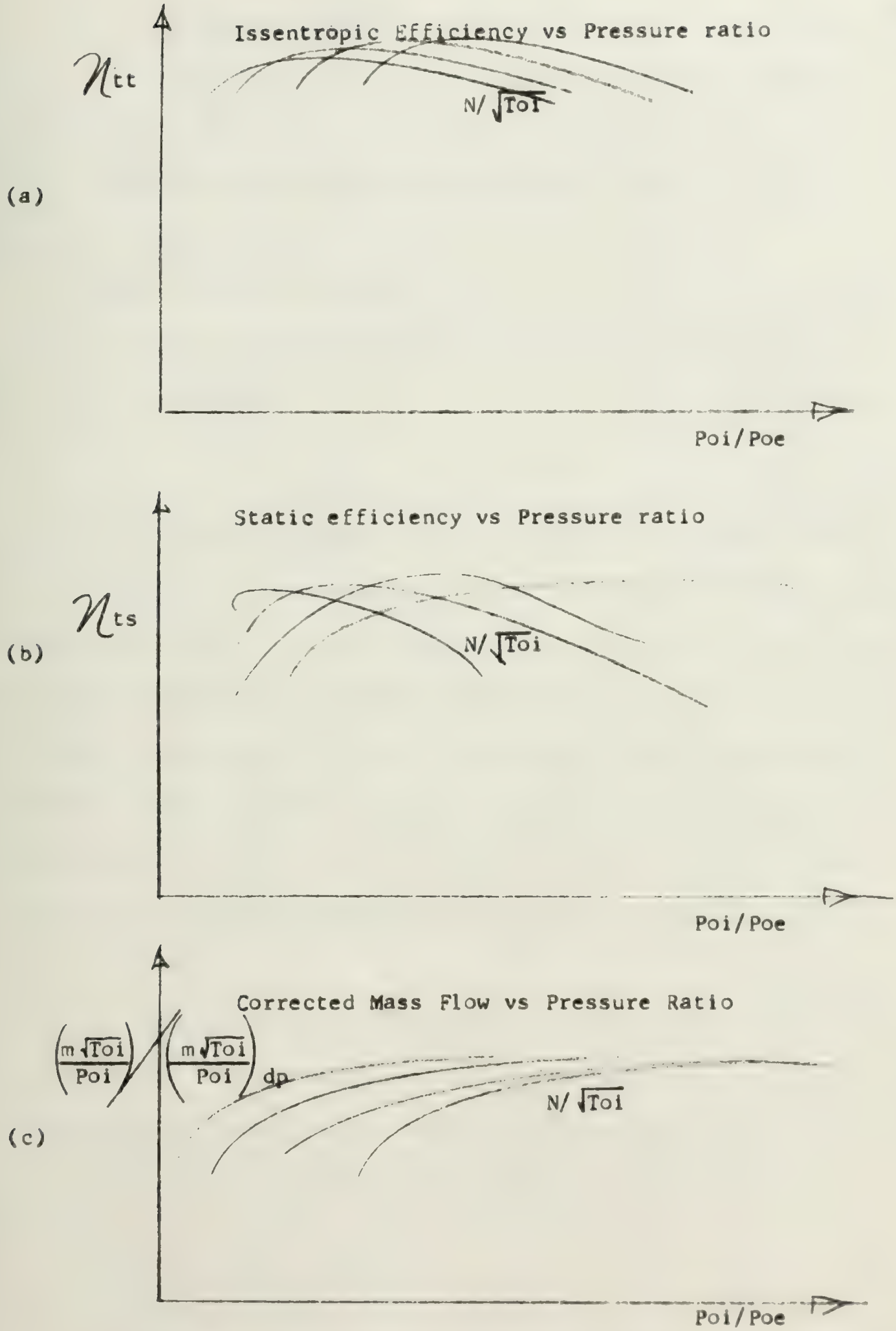


Figure 3-7. Performance Curves for Axial Turbine (a) Issentropic efficiency vs pressure ratio. (b) Static efficiency vs pressure ratio. (c) Corrected mass flow vs pressure ratio.

$$T_2 = To2(P_2/Po2)^{\frac{\gamma-1}{\gamma}} \qquad (3.3\text{-}2)$$

(5) Subroutine PLOSS is now entered to get Yt (pressure loss coeffiecient).

(6) Po2 can be determined from known values of Yt and (P_2 /Po2) from equation (3.3-3)

$$Po2 = Po1/(Y_t(1-P_2/Po2) + 1) \qquad (3.3\text{-}3)$$

(7) The mass flow parameter Q2 can now be determined.

$$Q2 = \frac{\dot{m}\sqrt{To}}{A_2 Po} \qquad (3.3\text{-}4)$$

$$\text{where } A_2 = An_2 \cos\alpha_2 \qquad (3.3\text{-}5)$$

(8) From the compressible flow tables for the value of Q_2 the Mach number can be determined, and if this value is close to the assumed Mach number the inlet conditions to the rotor can be solved for the new values of V_2, ρ_2, P_2, Mach number, and T_2 will be used to iterate the process until the assumed Mach number approximately equals the calculated value. Also as the Mach number approaches (1) a calculation will be performed to see if the row is choked. (ie; maximum flow for given parameters). This will be covered in section 3.3c.

Now that the exit Mach number has been determined the exit conditions of the nozzle can be determined, which will be the inlet conditions to the rotor. Where V_2 is determined from equation (3.3-1), T_2 from equation (3.3-2) and P_2 from compressible flow data.

$$P_2 = Po2(P_2/Po2) \qquad (3.3\text{-}6)$$

$$\rho_2 = \frac{P_2}{RT_2} \qquad (3.36a)$$

3.3b Flow through the rotor

(1) With α_2 and V_2 known the relative rotor angle β_2 can be calculated.

$$\tan\beta_2 = \tan\alpha_2 - \frac{Um_2}{V_2\cos\alpha_2} \qquad (3.3\text{-}7)$$

where $Um = r_{m2}\omega$

and determine the incidence angle (i,) where β_2' is the blade angle and $i = \beta_2 - \beta_2'$

(2) The relative velocity W_2 and relative total temperature, can then be calculated.

$$W_2 = (V_2\cos\alpha_2)^2\ (1 + \tan^2\beta_2) \qquad (3.3\text{-}8)$$

$$To2_{rel} = T_2 + \frac{W_2^2}{2goJCp} \qquad (3.3\text{-}9)$$

(3) $W_2/\sqrt{To2_{rel}}$ can be calculated, which will be used to enter the gas tables to get $P_2/Po2_{rel}$ which will allow $Po2_{rel}$ to be calculated.

(4) The same procedure of assuming exit Mach number and reiterating until the assumed Mach number equals the calculated one is followed. $Po3_{rel}$, β_3, W_3, M_3rel, and Q_{3rel} will then be known. From this relative Mach number $(P_3/Po3_{rel})$ can be determined, which will enable P_3 to be solved for. The absolute parameters α_3, V_3, $Po3$, T_3 and $To3$ can then be calculated.

$$\tan\alpha_3 = \tan\beta_3 + \frac{Um}{W_3\cos\beta_3} \qquad (3.3\text{-}10)$$

where $Um = r_{m3}\omega$

$$V_3 = (W_3 \cos\beta 3)^2 (1 + \tan^2\alpha 3) \qquad (3.3\text{-}11)$$

$$T_3 = To3_{rel} - \frac{W^2}{2goJCp} \qquad (3.3\text{-}12)$$

$$Po3 = P_3 (To3/T_3)^{\frac{\gamma}{\gamma - 1}} \qquad (3.3\text{-}13)$$

(5) If this is the last stage, efficiency η can be calculated by equations (3.3-14) and (3.3-15). If not the exit conditions will determine the inlet conditions to the nozzle of the next stage. This process will be iterated until the parameters have been determined for every stage in the turbine..

$$\eta tt = \frac{(Toi - Toe)}{Toi\left[1 - (Poe/Poi)^{\frac{\gamma-1}{\gamma}}\right]} \qquad (3.3\text{-}14)$$

$$\eta ts = \frac{(Toi - Toe)}{Toi\left[1 - (Pe/Poi)^{\frac{\gamma-1}{\gamma}}\right]} \qquad (3.3\text{-}15)$$

3.3c Determination of whether a row of turbine blades have choked is carried out when the Mach number approaches (1). For the computer program this process will be carried out when the Mach number is greater than 0.9.

(1) Select a slightly higher value of Q ($\frac{\dot{m}\sqrt{To}}{APo}$) calling it Q'.

(2) With this Q' enter the compressible flow tables to get corresponding values of P/Po and solve for Po_{in}/Po_{out} assuming Yt remains constant.

(3) Now calculate the new mass flow $\dot{m}'$. If this is less than $\dot{m}$ the flow has choked. Yt and Q will be assumed to remain constant with the flow going supersonic at the exit of the blade row. If $\dot{m}'$ is not less than $\dot{m}$ calculations will be resumed as was illustrated in section (3.3a) and (3.3b).

(4) Enter compressible flow tables with Q for supersonic flow to get corresponding values of (P_{out}/Po_{out}), $V_{out}/\sqrt{To_{out}}$, and M_{out}. From equation (3.3-3) determine Pout. With equation (3.3-4) Aout can be determined. Since Aout = $A_{annulus}\cos\alpha$, α can be solved for in equation (3.3-16). The calculations are then resumed in the same manner as in section (3.3a) and (3.3b). The validity of this method depends on whether Q and Yt remain constant after the turbine blade row has choked.

$$\alpha = \cos^{-1}\left(\frac{\dot{m}\sqrt{To_{out}}}{A_{annulus}PoQ}\right) \qquad (3.3\text{-}16)$$

Chapter 4

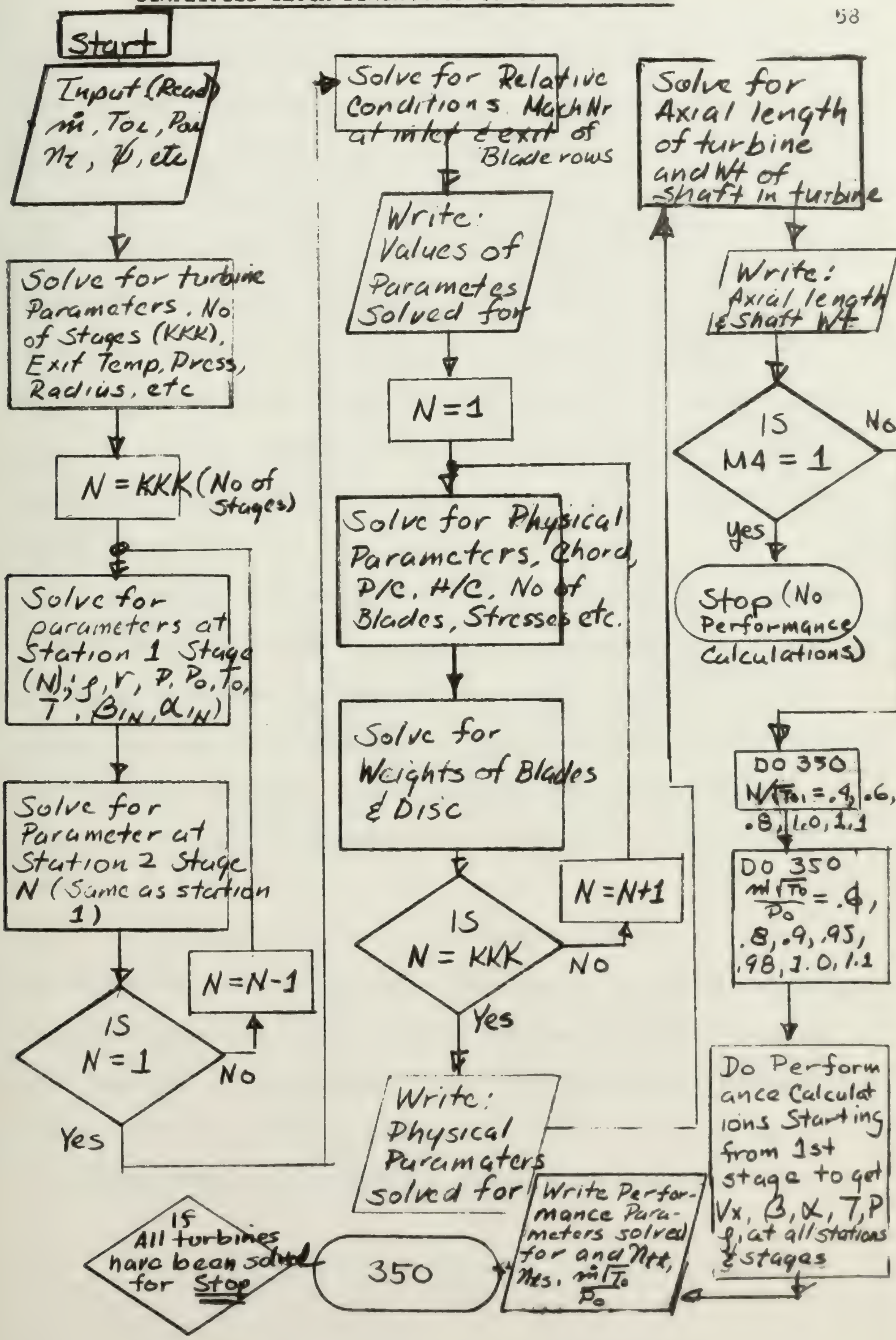
Operation of Computer Program

4.1 Chapters 1, 2, and 3 described how the calculations are performed in the computer program. This chapter will show how the flow of information is passed through the computer program to get the desired results. This information is not needed to use the computer program since that is covered in Appendix (2).

4.2 The steps of calculations in the computer are in the same sequential order as illustrated in chapters 1 through 3. This is shown in the simplified block diagram figure (4-1)

4.3 The method used in the computer program to interpolate curves is a 4 point Lagrange Polynomials with a worse case of a linear interpolation due to break down of Lagrange Polynomials for monatomic increasing or decreasing function. Subroutine FIG and BK are used to do this interpolating. Subroutine FIG selects the 4 data points closest to the argument X for passing to subroutine BK which actually does the interpolating to get the ordinate Y as an output. If the argument exceeds the limits of the data points the value closest to the argument X is used to get the ordinate Y. The reason this method was chosen over finding formulas by least squares or simular methods is this method can be adapted to changes in data without solving for new formulas or coefficients. The Lagrange Polynomials uses a monatomicly increasing base to get the ordinate Y. If the base is not monatomicly increasing such as

SIMPLIFIED BLOCK DIAGRAM OF COMPUTER PROGRAM



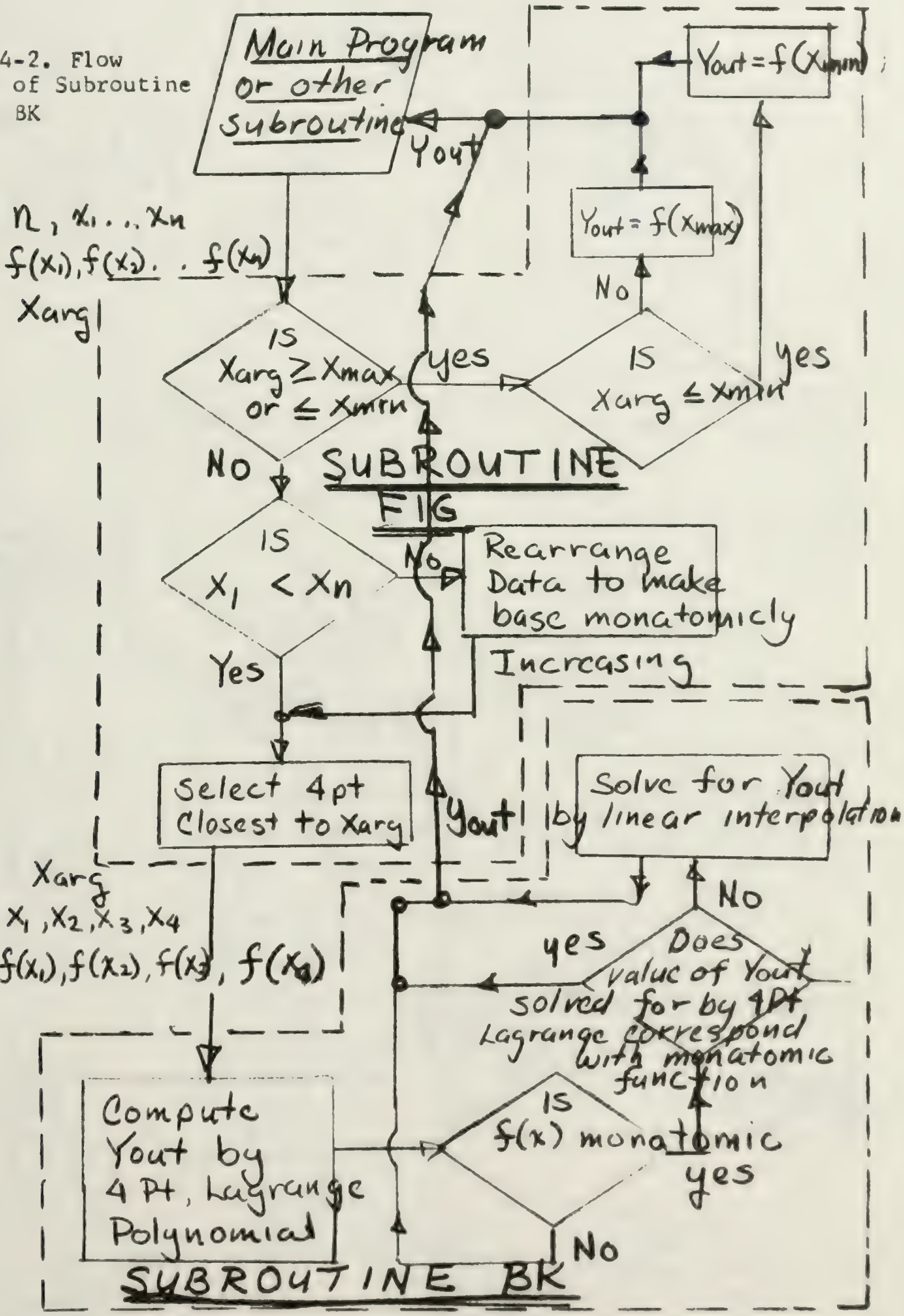
values of Mach Number vs Ps/Po, subroutine FIG rearranges the base so that the base is monatomicly increasing and the ordinate values are in corresponding relationship with the base. For values of base such as ($\dot{m}\sqrt{Toi}$)/APoi) which both increase and decrease the data points are divided into two parts with the part that increases as one set of data points and the part that decreases as another. The ordinate does not have to be a monatomic function. The problem of increasing and decreasing bases can be encountered in the performance estimations because the base and ordinate are interchanged in some of the steps. Figure 4-2 illustrates how subroutine FIG and 3K are used to interpolate data.

4.4 Figure (4-3) illustrates the method the computer program uses to determine the flow area at station 1. In most cases for a value of epsilon (ϵ) = .001 the convergence is reached in less than 10 iterations. This method is used for solving for the exit flow area and also for station 2. The method for solving the other parameters were will documented in chapers 1 thru 3 and will not be repeated here.

4.5 From output generated by the computer program, it is felt that the computer program can be very useful from early preliminary design to start of detailed design, since it has the versatility to accept more input data as the designer firmly sets the characteristics of the Turbine. As for cooling requirements it is felt that compensations in the input data could account for losses attributed to cooling.

BLOCK DIAGRAM OF SUBROUTINE FIG AND BK FOR INTERPOLATING FUNCTIONS f(x) from MAIN PROGRAM OR OTHER SUBROUTINES

Figure 4-2. Flow Diagram of Subroutine FIG and BK



Block Diagram of Adjusting Flow Area To Match Axial Velocity Vx at Station 1 For Constant Hub Turbine

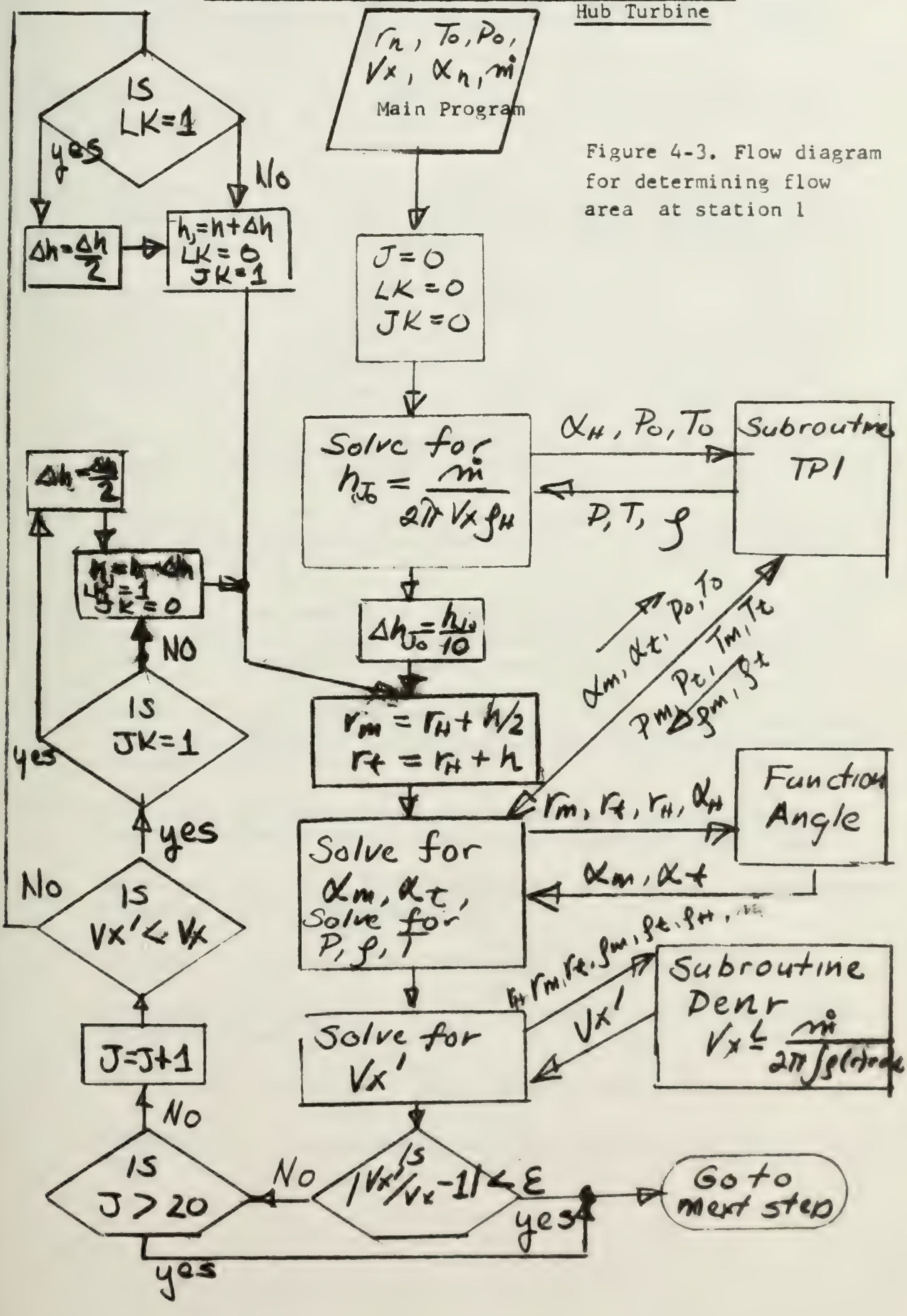


Figure 4-3. Flow diagram for determining flow area at station 1

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APPENDIX I

Symbols and Notation used in this Text.

SYMBOLS USED IN TEXT

A	Area
C	Chord of turbine blade
Cp	Specific heat (btu/lbm°R)
go	Constant in Newtons Law 32.174 (ftlbm)/(lbfsec^2)
h	Blade height
ho	Stagnation Enthalpy
H/C	Aspect ratio
i	Incidence angle
I	Moment of inertia
J	Energy conversion factor 778.16 (ftlbf)/(btu)
k	radius of gyration
M	Mach Number
M_{crit}	$Vx/(\frac{2}{\gamma+1}\, goRTo)^{\frac{1}{2}}$
$\dot{m}$	Mass Flow
N	Number of Stages
n	Number of Stage
Po	Stagnation Pressure
P	Static Pressure
P/C	Pitch to Chord ratio
R	Gas constant(ftlbf)/(lbm°R) $\frac{\gamma-1}{\gamma}JCp$
Q	Corrected mass flow $\dot{m}\sqrt{To}/PoA$
To	Stagnation Temperature
T	Static Temperature

To	Thickness of Outer Rim
Ti	Thickness of Inner Rim
SM	Non Dimensional Section Modulus
U	Blade Speed
V	Velocity
Vx	Axial Velocity
W	Relative Velocity
Wo	Width of Outer Disc Rim
Wi	Width of Inner Disc Rim
Y	Pressure Loss
R	Radius
r	Radius
t	Thickness of Turbine Blade
t/C	Thickness to Chord Ratio
Z	Section Modulus
Zi	Thickness of Mid Section of Turbine Disc at Inner Radius
Zo	Thickness of Mid Section of Turbine Disc at Outer Radius
Z(r)	Thickness of Disc as a Function of Radius
α	Absolute Gas Angles (except section 3.2)
β	Relative Gas Angles (except section 3.2)
ξ	Stagger Angle
γ	Ratio of Specific Heats Gamma
η	Efficiciency
σ	Stress
ρ	Density
ψ	Psi Loading Coefficient $\equiv \frac{go J \Delta ho}{U_h^2}$

$\mathcal{R}$	Reaction
Ω	Speed (rpm)
ω	Speed (rad/sec)

Subscripts

i	Inlet
e	Exit
t	Total
s	Stage
p	Polytropic
s	Static
t	Tip
m	Mean
h	Hub
c	constant

APPENDIX II

User's Guide To the Computer Program with Comparison of Turbine Designed with this Computer Program to one which was Designed by Airesearch. Sample Input and Output of Turbine Designed by Computer Program

II-1 The computer program can be used to calculate physical and thermodynamic properties of an axial flow turbine.. It has an optional ability to do performance calculations. The optional phase is very expensive to operate since it does both design and off design calculations. From operating the computer program and comparing the cycle calculations with performance calculations the cycle calculations are within 3% of performance calculations at design point. For the early preliminary phases of turbine design it is recommended that just the cycle calculations and mechanical design phases be carried out with the computer program punching output cards to have data to perform the performance calculations at a later time

A second program which reads in the punched output cards in the same order as they were punched in the first program is provided to do only performance calculations. This allows the performance estimations to be carried out with running the complete program again.

For future references program #1 will refer to the complete computer program while program #2 will refer to the program which only does performance estimations. The complete computer program can not be operated in computers which have less than 210 k of memory.

II-2 Pages 71 to 76 show how the computer cards are to be punched. The 1st card is a label which will be printed out in the same content as it was entered on the computer card. Cards 2 thru 4 are the input data cards of known turbine parameters. Cards 5 thru NNN are the compressible flow tables and viscosity of the gases with corresponding temperatures. Starting from card 5, 1st the Mach Numbers are read in , 2nd the corrected mass flow $\dot{m}\sqrt{To}/PoA$, 3rd the pressure ratio P/Po,

4th the corrected velocity $V/\sqrt{To}$, 5th the temperatures which correspond to the viscosity data, 6th the viscosity data. Page 77 is a set of compressible flow tables and viscosity data for air.

II-3 Pages 78 thru 82 are comparison data of computer program designed turbine with one which was designed by Airesearch reference (20). As can be seen from the data some of the parameters are different because of lack of knowledge of some of the design parameters which was used in the design of the Airesearch Turbine, also some simplifications are incorporated into the computer program for solutions of output parameters.

II-4 A list of sample output and input is provided from page 83 to 93 for turbine which was compared with Airesearch turbine. As can be seen on page 91 of output data, the performance data is very similar to the cycle calculations at design point. This justifies the argument of doing only cycle calculations and mechanical calculations when off design data is not required. Figure II-3 is a plot of the data points from performance calculations. Where some of the curves are discontinuous is caused by a limit of 10 iterations for solution at a blade row..

Input Data Cards

* (Must be specified)

(If value of parameter is not known place value to right of # on computer card)

Card 1

Column 1-80	Alphanumeric label (ie, "Gas Turbine number 1")
	# Blank Card

Card 2

Column 1*	M1 (Integer)
	0 compressible flow data to be entered.
	1 No compressible flow data to be entered.
Column 2 *	M2 (Integer).
	0 Power in horse power specified.
	1 Pressure ratio specified.
Column 3 and 4	Blank
Column 5 *	M (Integer) Type of turbine.
	1 Constant hub
	2 Constant mean
	3 Constant tip

Note Where instructions inform user to place dummy values on cards these values are used to inform computer that they are not specified and to perform optional calculations to determine the parameter.

Column 6-10	KLM (Integer right justified)
(leave blank if M1 = 1)	Number of compressible flow elements to be entered. (ie num-number of Mach Numbers to be en-entered) (Maximum 100)
Column 11-15	KTM (Integer right justified)
(leave blank if M1 = 1)	Number of Temperatures at which values of (viscosity) x $10^7 \frac{lbm}{sec\ ft.}$ is defined.
Column 16-20 *	Gamma γ (F5.3)
Column 21-25 *	CP (Btu/lbm °R) (F5.3)
Column 26-35	Power (Horse Power) (F10.1) if
(lbm/sec ft)	M2 = 0 this must be specified # 9000.
Column 36-45 *	W (mass flow) (lbm/sec) (F 10.3)
Column 46-50 *	TC (thickness to chord ratio) (F5.3), normally about # 0.2
Column 51-55 *	TET (thickness of trailing edge to pitch ratio) (F5.3) normally about # 0.02
Column 56-60 *	TIPCLA (Tip clearance) (in) (F5.3) normally about # 0.015

Card 3

Column 1-5 *	ψ PSI (F5.3)
	Normally between 1.5 and 2.9
	# 2.0
Column 6-10 *	RTE (Max Tip raduis in ft at exit)
	(F5.3)
Column 11-15 *	Ratio T (R_{te}/R_{he}) Ratio of Tip to
	hub at exit (F5.3) # 1.5
Column 16-20	$\mathcal{R}$ hub (exit) Reaction at hub (F5.3)
	normally between .00 to 0.4 # .05
Column 21-30 *	OMEGA (RPM) (F 10.0)
Column 31-32	KLM1 (INTEGER) <u>Right justified</u> if
	Compressible flow data provided
	the value at which $\frac{\dot{m}\sqrt{T_{oi}}}{P_{oi}A}$
	is a maximum in (for
	sample problem KLM1 = 50) (Maximum 70)
Column 33-39	Blank
Column 40 *	M4 (Integer)
	0 performance calculations to be per-
	formed.
	1 No Performance Calculations to be
	performed.
Column 41-45 *	SPECWT (Specific Weight of turbine
	disc and blades (lb/in^3) (F5.3)
	# normally about 0.3

Column 46-50 *	Y MOD (Young's Modulus psi) (f 15.0) Normally about # 30000000.
Column 61-70 *	C1 (Value of allowable blade stress in psi) (F 10.0) Normally about # 50000.
Column 71-80 *	C2 (Value of allowable blade steady stress in PSI) (F 10.0) Normally about # 100000.

<u>Card 4</u>

Column 1-5 *	ENT (Value of total efficiency desired. # .9
Column 6-15	Radius of Shaft in ft (F 10.5) # - 0.1 if not known
Column 16-20	P ratio (Pressure Ratio) (F5.3) if M2 = 1 this must be specified # 1.5
Column 21-30 *	ULTSRE (Ultimate Tensile Strength of Material of Disc (psi) Value for disc stress is calculated from this. (F10.0)

$$\sigma_{avg} = \frac{.75\ \text{ULTSRE}}{(1.2)^2}$$

Normally about # 130000.

Column 31-35	ALPHAH (Exit angle in radians) (F5.3) Normally between (0.0 to - .3) # - .1
Column 36-45	EMACH = $\dfrac{V_x}{\sqrt{\dfrac{2}{\gamma+1} g_o R T_o}}$ Normally Between .2-1.0 #-.5

Column 46 — M3 (Integer)

0 Normal Blades

1 Shrouded Rotor Blades. #0

Column 47-48 * — NKL (Number of turbines to be designed by computer program. (Integer right justified) All sets of cards except for last turbine design will have 0 in column 48. The last set of cards will have the number of sets that were entered. This allows the computer to stop after completing the last turbine design.

Column 49-50 — N (Number of stage Integer right justified) (Maximum 10) If this value is not known, enter 0 and computer will solve for number of stages. #0

Column 51-55 * — AREARA (F5.4)

Tip to base area ratio of turbine blade normally between .25 to .35

\# .25

Column 56-60 — TOO (Gives radial thickness of outer rim of disc. by To = Wo/TOO normally between 2 to 4 (F5.3) # - 5.

Cards 5-NNN

These cards are optional. If performance calculations are to be performed they must be furnished. If more than one turbine is to be designed compressible flow data must only be furnished for 1 st turbine and the value of M1 on card 2 for each following turbines will be "1". If the compressible flow parameters are different a set must be furnished. A set of compressible flow data and viscosity data for air are provided with the computer program.

Card 5 - N	RMAC (Mach Numbers) (20F4.2) same number as KLM
Card (N + 1)-K	WTAP (10F8.5) $\frac{\dot{m}\sqrt{To}}{PoA}$ $\frac{lbm\sqrt{^{o}R}}{sec\ lbf}$ Same numbers as KLM
Card (K+1) -J	PSPT (Ps/Po) (10F8.5) same number as KLM
Card (J+1)-L	VELTOT $(V/\sqrt{To})$ (10F8.5) $\frac{(ft/sec)}{\sqrt{^{o}R}}$ same number as KLM
Card (L + 1) - LL	TEM (^{o}R) (20F5.0) same number as KTM temperature values that correspond with viscosity data
Card (LL + 1)-NNN	V (Viscosity of fluid (lbm.sec/ft)x 10^{7}) (20F5.0)

Compressible Flow Tables for Combustion Products

reference (2)

MACH NO	W*SQRT(T)/(A*P) $\frac{lbm\sqrt{°R}}{sec\ lbf}$	PS/PT	V/SQRT(T) $(ft/sec)/\sqrt{°R}$
0.02000	0.01811	0.99973	0.96151
0.04000	0.03596	0.99893	1.91184
0.06000	0.05388	0.99760	2.86589
0.08000	0.07171	0.99574	3.82740
0.10000	0.08945	0.99335	4.77028
0.12000	0.10706	0.99040	5.72284
0.14000	0.12448	0.98700	6.67094
0.16000	0.14154	0.98317	7.61008
0.17000	0.15885	0.97870	8.56787
0.20000	0.17562	0.97380	9.50329
0.22000	0.19226	0.96835	10.45287
0.24000	0.20849	0.96260	11.36668
0.26000	0.22446	0.95630	12.31328
0.28000	0.24049	0.94950	13.26734
0.30000	0.25612	0.94200	14.22884
0.32000	0.27135	0.93440	15.14564
0.34000	0.28590	0.92650	16.04750
0.36000	0.30026	0.91800	16.99411
0.38000	0.31435	0.90920	17.90344
0.40000	0.32763	0.90030	18.82024
0.42000	0.34118	0.89080	19.75192
0.44000	0.35386	0.88100	20.63144
0.46000	0.36627	0.87060	21.54077
0.48000	0.37821	0.86000	22.45010
0.50000	0.38948	0.84950	23.33708
0.52000	0.40061	0.83860	24.27625
0.54000	0.41108	0.82720	25.16321
0.56000	0.42114	0.81570	26.05019
0.58000	0.43067	0.80400	26.95207
0.60000	0.43979	0.79220	27.80922
0.62000	0.44838	0.78020	28.65892
0.64000	0.45669	0.76780	29.54590
0.66000	0.46421	0.75550	30.41052
0.68000	0.47159	0.74270	31.29750
0.70000	0.47796	0.73070	32.09502
0.72000	0.48433	0.71800	32.94472
0.74000	0.49010	0.70520	33.80190
0.76000	0.49560	0.69140	34.65160
0.78000	0.50030	0.67910	35.47894
0.80000	0.50459	0.66650	36.29883
0.82000	0.50815	0.65500	37.05164
0.84000	0.51170	0.64080	37.93861
0.86000	0.51479	0.62760	38.76595
0.88000	0.51734	0.61410	39.60822
0.90000	0.51948	0.60250	40.39828
0.92000	0.52123	0.58900	41.14365
0.94000	0.52257	0.57550	42.03061
0.96000	0.52337	0.56500	42.70889
0.98000	0.52391	0.55100	43.41698
1.00000	0.52418	0.54000	44.16234
1.02000	0.52391	0.52800	44.98222
1.04000	0.52337	0.51700	45.69031
1.06000	0.52257	0.50400	46.36113
1.08000	0.52136	0.49100	47.17357
1.10000	0.51989	0.48000	47.85184
1.12000	0.51801	0.46820	48.59720
1.14000	0.51599	0.45650	49.34256
1.16000	0.51358	0.44530	50.02827
1.18000	0.51076	0.43330	50.74382
1.20000	0.50795	0.42250	51.39229

for $\gamma = 1.333$

$g = 37.174\ \frac{ft}{sec}$

$C_p = .274\ \frac{Btu}{lbm\,°R}$

Viscosity of Air from Reference (14)

Temperature (°R)	Viscosity $\times 10^7\ \frac{lbm}{sec\ ft}$
400	100
600	135
800	166
1000	192
1200	218
1400	242
1600	264
1800	284
2000	302
2200	320
2400	338

COMPARISON OF COMPUTER PROGRAM TURBINE DESIGN WITH AIRESEARCH 9000 HP FREE VORTEX AXIAL FLOW TURBINE

Inlet Conditions

Gas	Air
Poi(psi)	312.5
Toi(^{o}R)	1767.8
m(lb/sec)	119.421

Design Parameters

ψ	1.8
α_e	0.0

Assumed Design Parameters

η_{tt}	0.9168
Cp(btu/lb^{o}R)	.2715
Gamma γ	1.333

Results

Figure II-1 is a comparison of the turbine wheel dimensions.

Figure II-2 is a comparison of design point performance calculations of total and static efficiencies as a function of tip clearance.

COMPARISON OF OUTPUT DATA FROM COMPUTER PROGRAM WITH AIRESEARCH GAS TURBINE

Parameter	Airesearch	Computer Program
T_{oe}(^{o}R)	1571.4	1554.0
M_{crit} at exit	-	.292
P_{oe} (psi)	186.0	177.3
	Velocity Diagrams	
hub(station 1)		
radius(ft)	.4383	.429
β_1 (deg)	-62.02	-63.96
α_1 (deg)	0.0	0.0
tip(station 1)		
radius(ft)	.530	.429
β_1 (deg)	-67.15	-70.93
α_1 (deg)	0.0	0.0
Hub(station 3)		
radius(ft)	.4383	.429
β_3 (deg)	-60.95	-63.96
α_3 (deg)	0.0	0.0
Tip(station 3)		
radius(ft)	.6215	.636
β_3 (deg)	-68.26	-72.99
α_3 (deg)	0.0	0.0
σ_{cf}(psi)	37,400.	37,896.
Wheel Weight(lbf)	18.7	21.46

Conclusions:

Most of the descrepancies in parameter values can be attributed to different input values for the computer model. This is caused by not knowing the assumptions or definitions that were used in designing the Airesearch Gas Turbine. From this limited comparison it is felt that the computer model can be used for designing marine gas turbines since it has the versatility to change parameters which are attributed to specific turbines. For high performance turbines (aircraft) it should be compared with known aircraft turbines to verify the validity of the computer program and adjust the variable parameters to match them.

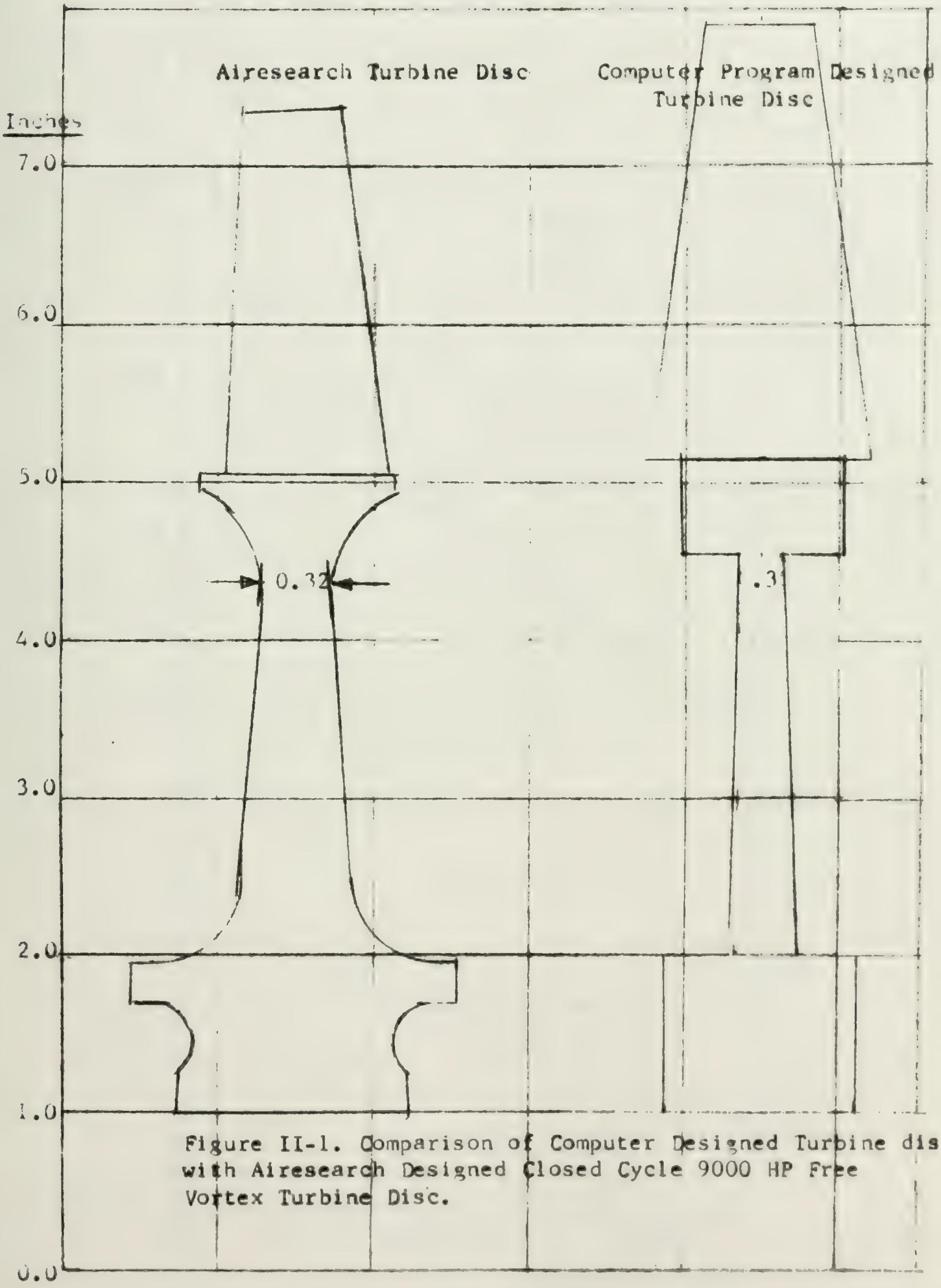

Figure II-1. Comparison of Computer Designed Turbine disc with Airesearch Designed Closed Cycle 9000 HP Free Vortex Turbine Disc.

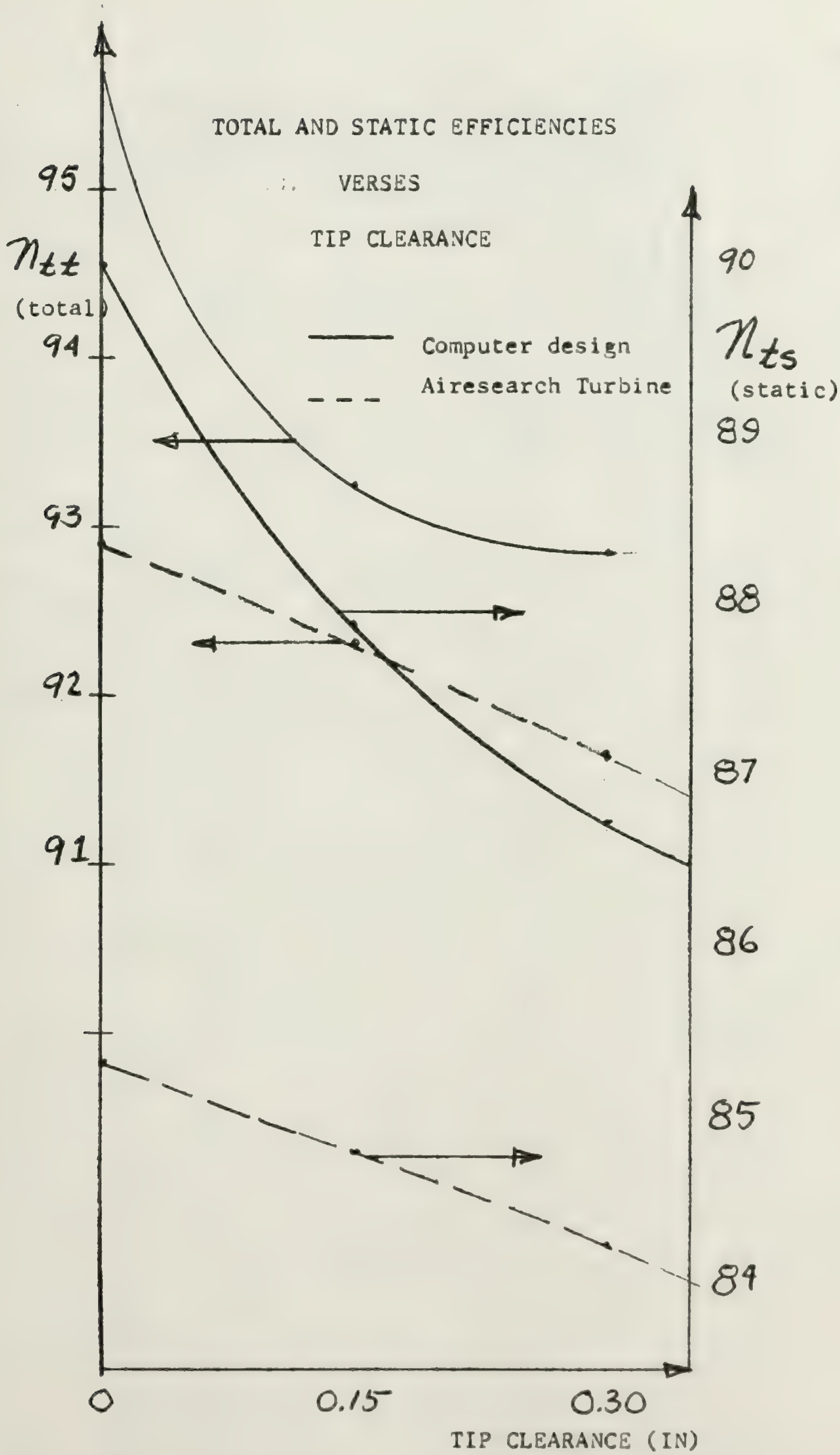

Figure II-2, Comparison of Efficiencies verses Tip Clearance of Performance Calculations.

Input Data Cards to Run 9000 HP turbine with Performance Calculations and 13673 HP turbine with Performance Calculations with same compressible flow data

```
$ENTRY <-- Control Card                                                                 Card
9000 HP SINGLE STAGE GAS TURBINE ENGINE        Turbine #1                                  1
00  1   60   111.333.27159000.       119.42     .2    .02   .015 1767.8      312.48        2
1.8  .62161.418.1   20000.     50         0.287 29000000.        20000.      93000.        3
.9168.08333     1.680130000.     .000 .292          0 0 1.25    .1                         4
  0.020.040.060.080.100.120.140.160.170.200.220.240.260.280.300.320.340.360.380.40         5
M 0.420.440.460.480.500.520.540.560.580.600.620.640.660.680.700.720.740.760.780.80         6
  0.820.840.860.880.900.920.940.950.981.001.021.041.061.081.101.121.141.161.181.20         7
   0.01811 0.03596 0.05388 0.07171 0.08945 0.10706 0.12448 0.14154 0.15885 0.17562         8
   0.19226 0.20849 0.22446 0.24049 0.25612 0.27135 0.28590 0.30026 0.31435 0.32763         9
m√To 0.34118 0.35386 0.36627 0.37821 0.38948 0.40061 0.41108 0.42114 0.43067 0.43979       10
AP 0.44838 0.45669 0.46421 0.47159 0.47796 0.48433 0.49010 0.49560 0.50030 0.50450        11
   0.50815 0.51170 0.51479 0.51734 0.51948 0.52123 0.52257 0.52337 0.52391 0.52414        12
   0.52391 0.52337 0.52257 0.52136 0.51989 0.51801 0.51599 0.51358 0.51076 0.50795        13
   0.99973 0.99893 0.99760 0.99574 0.99335 0.99040 0.98700 0.98317 0.97870 0.97380        14
   0.96835 0.96260 0.95630 0.94950 0.94200 0.93440 0.92650 0.91800 0.90920 0.90030        15
Ps 0.89080 0.88100 0.87060 0.86000 0.84950 0.83860 0.82720 0.81570 0.80400 0.79220        16
Po 0.78020 0.76780 0.75550 0.74270 0.73070 0.71800 0.70520 0.69140 0.67910 0.66650        17
   0.65500 0.64060 0.62760 0.61410 0.60250 0.58900 0.57550 0.56500 0.55100 0.54000        18
   0.52800 0.51700 0.50400 0.49100 0.48000 0.46820 0.45650 0.44530 0.43330 0.42250        19
   0.96151 1.91184 2.86589 3.82740 4.77028 5.72284 6.67094 7.61008 8.56787 9.50320        20
  10.4528711.3666812.3132813.2673414.2288415.1456416.0475016.9941117.9034418.82024        21
V 19.7519220.6314421.5407722.4501023.3370824.2762525.1632126.0501926.9520727.80925        22
√To 28.6589229.5459030.4105231.2975032.0950232.9447233.8019034.6516035.4789436.29683    23
  37.0516437.9386138.7659539.6082240.3982841.1436542.0306142.7088943.4169844.16234        24
  44.9822245.6903146.3611347.1735147.8518448.5972049.3425650.0282750.7438251.39229        25
T 400. 600. 800. 1000.1200.1400.1600.1800.2000.2200.2400.     Temperature                 26
μ 100. 135. 166. 192. 218. 242. 264. 284. 302. 320. 338.      Viscosity x10^7             27
13673 HP SINGLE STAGE AIRCRAFT GAS TURBINE ENGINE  Turbine #2                              1
10   2   60   111.333.274 13673.      100.       .2    .02   .015 2960.       88.2         2
2.8  1.034 2.0 0.0  13855.    50          2.287 29000000.        45000.      93000.        3
0.9       .1   6.   130000.    -.5  -.25        0 2 1.25   .1                              4
```

Sample Input Data Cards

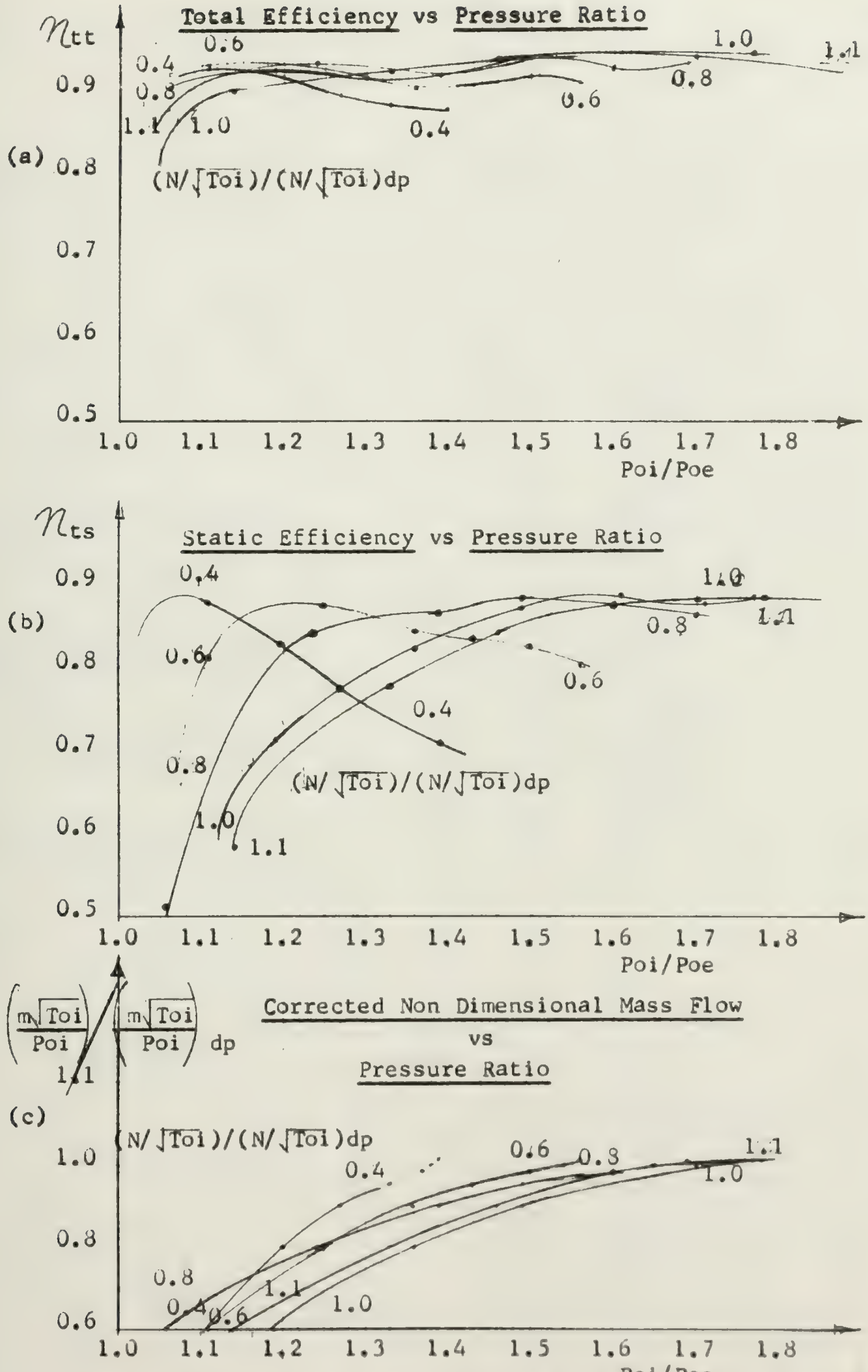

Figure II-3. Performance Curves from data calculated with Computer Program. (a) Issentripic Efficiency (b) Static Efficiency.(c) Corrected mass flow.

9000 HP SINGLE STAGE GAS TURBINE ENGINE

MASS FLOW(LB/S)	POWER(HP)	INLET TEMP(R)	EXIT TEMP(R)	INLET PRESS(PSI)	EXIT PRESS(PSI)	ISSEN EFFIC	POLY EFFIC
119.42	9000.	1768.	1554.	312.480	177.270	0.917	0.911

OMEGA(RPM)	GAMMA	CP(BTU/LBMR)	REACTION HUB	PSI	VX(FT/S)	CRIT MACH NO AT EXIT
20000.	1.333	0.2715	0.100	1.500	439.2	0.2920

LOCATION	STATION	STAGE	TOTAL TEMP	STATIC TEMP	TOTAL PRESS	STATIC PRESS	DENSITY	ALPHA	BETA	REACTION	RADIUS
1	1	1	1767.80	1753.61	312.48	302.56	0.4708	0.00	-62.90	0.100	0.429
2	1	1	1767.80	1753.61	312.48	302.56	0.4708	0.00	-67.96	0.382	0.518
3	1	1	1767.80	1753.61	312.48	302.56	0.4708	0.00	-70.93	0.549	0.607
1	2	1	1767.80	1561.03	306.51	151.49	0.3172	74.82	58.59	0.100	0.429
2	2	1	1767.80	1631.26	306.51	220.20	0.3683	71.20	20.24	0.428	0.538
3	2	1	1767.80	1659.05	306.51	243.51	0.3981	67.73	-32.94	0.605	0.648
1	3	1	1553.80	1539.61	177.27	170.68	0.3028	0.00	-63.36	0.100	0.429
2	3	1	1553.80	1539.61	177.27	170.68	0.3028	0.00	-69.30	0.466	0.557
3	3	1	1553.80	1539.61	177.27	170.68	0.3028	0.00	-72.99	0.647	0.686

LOCATION	STAGE	RELATIVE TOTAL TEMP FOR ROTOR INLET	EXIT	REAL MACH NO FOR STATOR INLET	EXIT	RELATIVE MACH NO FOR ROTOR INLET	EXIT
1	1	1613.25	1613.24	0.2204	0.9979	0.4493	0.5359
2	1	1647.37	1650.04	0.2204	0.7090	0.2436	0.6681
3	1	1689.19	1705.44	0.2204	0.5961	0.2692	0.8043

LOC	STAGE	STATOR ANGIN	GAS ANGIN	STATOR ANGOUT	GAS ANGOUT	ROTOR ANGIN	GAS ANGIN	ROTOR ANGOUT	GAS ANGOUT
1	1	0.0	0.0	74.7	74.8	58.6	58.6	-65.7	-64.0
2	1	0.0	0.0	71.6	71.2	20.2	20.2	-70.1	-69.4
3	1	0.0	0.0	69.6	67.7	-32.9	-32.9	-73.1	-73.0

THE DATA EXCEEDED THE LIMITS OF THE PROGRAM AND S/C IS ASSUMED TO EQUAL .7

ROW	STAGE	NO BLADES	TOTAL BLADE WTS
1	1	46	2.97

ROW	STAGE	CHORD1	CHORD2	CHORD3	HEIGHT	1-BEND FREQ	HARMONIC	P/C	H/C	BENDING STRESS
1	1	0.752	1.189	1.504	2.376	4076.6	14.0	0.728	1.997	5264.4

ROW	STAGE	NO BLADES	TOTAL BLADE WTS
2	1	43	7.52

ROW	STAGE	CHORD1	CHORD2	CHORD3	HEIGHT	1-BEND FREQ	HARMONIC	P/C	H/C	BENDING STRESS	CENTRIFUGAL STRESS
2	1	1.574	1.245	0.787	2.849	3637.9	10.9	0.772	2.289	2426.5	37895.5

WTOBIN	WTIRIN	WTMID	WTDISC	WTOT	RTIP	RHUB	BURST SPEED	BS/OMEGA
4.65	3.34	5.95	13.94	21.46	0.667	0.429	28723.	1.44

DISC DIMENSIONS FROM RSHAFT TO RHUB(INCHES)

R(1) = 1.00	Z(1) = 1.229
R(2) = 2.00	Z(2) = 1.228
R(3) = 2.00	Z(3) = 0.459
R(4) = 2.26	Z(4) = 0.446
R(5) = 2.53	Z(5) = 0.433
R(6) = 2.79	Z(6) = 0.418
R(7) = 3.06	Z(7) = 0.403
R(8) = 3.32	Z(8) = 0.387
R(9) = 3.58	Z(9) = 0.370
R(10) = 3.85	Z(10) = 0.353
R(11) = 4.11	Z(11) = 0.336
R(12) = 4.38	Z(12) = 0.315
R(13) = 4.64	Z(13) = 0.300
R(14) = 4.64	Z(14) = 1.023
R(15) = 5.15	Z(15) = 1.023

Output: from cycle and mechanical design of turbine

STAGE	STATION	DISTANCE FROM STATION 1, STAGE 1
1	1	0.0000
1	2	1.7671
1	3	3.5342

LENGTH(IN)	RADHUBINLET(IN)	RADTIPINLET(IN)	RADHUBEXIT(IN)	RADTIPEXIT(IN)	WTOFSHAFT(LB)	WTOF DISCS+BLADES(LB)
3.53	5.15	7.28	5.15	8.23	3.21	24.37

Output : From Performance Calculations

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 0.40 PO1/PO2= 1.11

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1736.6	306.5	311.3	220.2	289.3	0.368	0.455	71.2	70.9	20.2	37.5
3	1	1553.8	1724.7	1539.6	1727.3	177.3	280.8	170.9	279.2	0.303	0.442	0.0	-1.3	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	213.	181.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 0.40 PO1/PO2= 1.20

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1705.4	306.5	310.4	220.2	269.0	0.368	0.430	71.2	70.9	20.2	54.2
3	1	1553.8	1694.5	1539.6	1696.1	177.3	259.5	170.9	254.4	0.303	0.411	0.0	-39.2	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	302.	262.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 0.40 PO1/PO2= 1.27

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1680.2	306.5	309.7	220.2	253.1	0.368	0.411	71.2	71.0	20.2	58.5
3	1	1553.8	1675.7	1539.6	1660.3	177.3	245.6	170.9	236.7	0.303	0.389	0.0	-47.4	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	356.	309.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 0.40 PO1/PO2= 1.33

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1665.8	306.5	309.2	220.2	242.6	0.368	0.398	71.2	71.0	20.2	60.0
3	1	1553.8	1662.0	1539.6	1640.4	177.3	235.7	170.9	223.7	0.303	0.372	0.0	-50.9	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	383.	341.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 0.40 PO1/PO2= 1.37

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1651.9	306.5	308.9	220.2	233.7	0.368	0.387	71.2	71.1	20.2	61.1
3	1	1553.8	1651.2	1539.6	1623.6	177.3	227.0	170.9	212.7	0.303	0.357	0.0	-53.2	-69.4	-69.0

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439	407	367

1	439.	407.	367.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 0.40 P01/P02= 1.38

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1639.5	306.5	308.6	220.2	229.8	0.368	0.381	71.2	71.1	20.2	61.8
3	1	1553.8	1649.1	1539.6	1619.0	177.3	227.1	170.9	210.9	0.303	0.355	0.0	-53.9	-69.4	-69.1

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	427.	377.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 0.40 P01/P02= 1.39

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1633.7	306.5	308.5	220.2	225.5	0.368	0.376	71.2	71.2	20.2	62.2
3	1	1553.8	1644.8	1539.6	1611.2	177.3	224.6	170.9	206.8	0.303	0.350	0.0	-54.8	-69.4	-69.1

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	436.	389.

FOR N/SQRT(T01) EQUAL TO 0.40

P01/P02	TOTAL EFFICIENCY	STATIC EFFICIENCY	N*SQRT(T01)/P01
1.11	0.9242	0.8796	0.600
1.20	0.9148	0.8292	0.800
1.27	0.8921	0.7769	0.900
1.33	0.8804	0.7477	0.950
1.37	0.8664	0.7203	0.980
1.39	0.8759	0.7178	1.000
1.39	0.8783	0.7099	1.010

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 0.60 P01/P02= 1.11

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1736.6	306.5	311.3	220.2	289.3	0.368	0.465	71.2	70.9	20.2	-16.1
3	1	1553.8	1726.8	1539.6	1720.5	177.3	282.4	170.9	278.3	0.303	0.441	0.0	51.4	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	213.	182.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 0.60 P01/P02= 1.25

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1705.4	306.5	310.4	220.2	269.0	0.368	0.430	71.2	70.9	20.2	32.6
3	1	1553.8	1690.3	1539.6	1675.1	177.3	250.6	170.9	247.6	0.303	0.403	0.0	2.8	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439	302	265

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 1        439.        302.        265.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1)= 0.60 PO1/PO2= 1.36

STATION  STAGE  TOTAL TEMPERATURE  STATIC TEMP(R)  TOTAL PRES(PSI)  STATIC PRES(PSI)  DENSITY(LB/FT**3)  ALPHA     BETA
   1       1      1767.8  1767.8    1753.6  1753.6    312.5  312.5    302.6  302.5       0.471 0.471   0.0   0.0 -68.0   0.0
   2       1      1767.8  1767.8    1631.3  1680.2    306.5  309.7    220.2  253.1       0.368 0.411  71.2  71.0  20.2  44.9
   3       1      1553.8  1649.9    1539.6  1641.1    177.3  229.5    170.9  224.7       0.303 0.374   0.0 -22.1 -69.4 -68.9
STAGE  VX STATION 1  VX STATION 2  VX STATION 3
  1         439.          356.          320.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1)= 0.60 PO1/PO2= 1.43

STATION  STAGE  TOTAL TEMPERATURE  STATIC TEMP(R)  TOTAL PRES(PSI)  STATIC PRES(PSI)  DENSITY(LB/FT**3)  ALPHA     BETA
   1       1      1767.8  1767.8    1753.6  1753.6    312.5  312.5    302.6  302.5       0.471 0.471   0.0   0.0 -68.0   0.0
   2       1      1767.8  1767.8    1631.3  1665.8    306.5  309.2    220.2  242.6       0.368 0.398  71.2  71.0  20.2  48.7
   3       1      1553.8  1630.7    1539.6  1618.3    177.3  218.3    170.9  211.8       0.303 0.357   0.0 -31.1 -69.4 -69.0
STAGE  VX STATION 1  VX STATION 2  VX STATION 3
  1         439.          382.          350.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1)= 0.60 PO1/PO2= 1.50

STATION  STAGE  TOTAL TEMPERATURE  STATIC TEMP(R)  TOTAL PRES(PSI)  STATIC PRES(PSI)  DENSITY(LB/FT**3)  ALPHA     BETA
   1       1      1767.8  1767.8    1753.6  1753.6    312.5  312.5    302.6  302.5       0.471 0.471   0.0   0.0 -68.0   0.0
   2       1      1767.8  1767.8    1631.3  1651.9    306.5  308.9    220.2  233.7       0.368 0.387  71.2  71.1  20.2  51.4
   3       1      1553.8  1612.5    1539.6  1594.7    177.3  208.6    170.9  199.5       0.303 0.341   0.0 -38.5 -69.4 -69.1
STAGE  VX STATION 1  VX STATION 2  VX STATION 3
  1         439.          407.          385.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1)= 0.60 PO1/PO2= 1.54

STATION  STAGE  TOTAL TEMPERATURE  STATIC TEMP(R)  TOTAL PRES(PSI)  STATIC PRES(PSI)  DENSITY(LB/FT**3)  ALPHA     BETA
   1       1      1767.8  1767.8    1753.6  1753.6    312.5  312.5    302.6  302.5       0.471 0.471   0.0   0.0 -68.0   0.0
   2       1      1767.8  1767.8    1631.3  1639.5    306.5  308.6    220.2  228.8       0.368 0.381  71.2  71.1  20.2  53.3
   3       1      1553.8  1604.7    1539.6  1583.2    177.3  203.2    170.9  192.5       0.303 0.332   0.0 -41.7 -69.4 -69.2
STAGE  VX STATION 1  VX STATION 2  VX STATION 3
  1         439.          427.          403.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1)= 0.60 PO1/PO2= 1.56

STATION  STAGE  TOTAL TEMPERATURE  STATIC TEMP(R)  TOTAL PRES(PSI)  STATIC PRES(PSI)  DENSITY(LB/FT**3)  ALPHA     BETA
   1       1      1767.8  1767.8    1753.6  1753.6    312.5  312.5    302.6  302.5       0.471 0.471   0.0   0.0 -68.0   0.0
   2       1      1767.8  1767.8    1631.3  1633.7    306.5  308.5    220.2  225.5       0.368 0.376  71.2  71.2  20.2  54.0
   3       1      1553.8  1598.9    1539.6  1575.1    177.3  200.2    170.9  189.5       0.303 0.326   0.0 -43.2 -69.4 -69.2
STAGE  VX STATION 1  VX STATION 2  VX STATION 3
  1         439           436           414
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1	439.	436.	414.

FOR N/SQRT(TO1) EQUAL TO 0.60

PO1/PO2	TOTAL EFFICIENCY	STATIC EFFICIENCY	M*SQRT(TO1)/PO1
1.11	0.9291	0.8130	0.600
1.25	0.9236	0.8760	0.800
1.36	0.8994	0.8435	0.900
1.43	0.9052	0.8376	0.950
1.50	0.9046	0.8285	0.980
1.54	0.9052	0.8095	1.000
1.56	0.9076	0.8058	1.010

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 0.80 PO1/PO2= 1.06

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1736.6	306.5	311.3	220.2	299.3	0.368	0.455	71.2	70.9	20.2	-53.4
3	1	1553.8	1745.1	1539.6	1726.7	177.3	294.6	170.9	282.3	0.303	0.446	0.0	68.9	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	213.	180.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 0.80 PO1/PO2= 1.24

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1705.4	306.5	310.4	220.2	269.0	0.368	0.430	71.2	70.9	20.2	-6.2
3	1	1553.8	1682.0	1539.6	1672.4	177.3	252.2	170.9	246.5	0.303	0.402	0.0	42.9	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	302.	265.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 0.80 PO1/PO2= 1.39

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1680.2	306.5	309.7	220.2	253.1	0.368	0.411	71.2	71.0	20.2	19.9
3	1	1553.8	1640.1	1539.6	1631.8	177.3	225.1	170.9	220.5	0.303	0.369	0.0	16.3	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	356.	323.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 0.80 PO1/PO2= 1.49

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1665.8	306.5	309.2	220.2	242.6	0.368	0.398	71.2	71.0	20.2	28.8
3	1	1553.8	1611.3	1539.6	1601.5	177.3	209.8	170.9	204.7	0.303	0.349	0.0	-2.6	-69.4	-69.0

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439	383	365

1	439.	383.	365.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 0.80 P01/P02= 1.60

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1651.9	306.5	308.9	220.2	233.7	0.368	0.387	71.2	71.1	20.2	35.0
3	1	1553.8	1596.8	1539.6	1574.1	177.3	195.6	170.9	189.4	0.303	0.328	0.0	-16.2	-69.4	-69.2

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	407.	400.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 0.80 P01/P02= 1.64

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1639.5	306.5	308.6	220.2	228.9	0.368	0.381	71.2	71.1	20.2	39.1
3	1	1553.8	1575.2	1539.6	1560.2	177.3	190.0	170.9	182.9	0.303	0.320	0.0	-22.0	-69.4	-69.2

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	427.	416.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 0.80 P01/P02= 1.69

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1633.7	306.5	308.5	220.2	225.5	0.368	0.376	71.2	71.2	20.2	43.7
3	1	1553.8	1565.1	1539.6	1547.8	177.3	184.6	170.9	176.6	0.303	0.311	0.0	-26.3	-69.4	-69.3

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	436.	434.

FOR N/SQRT(T01) EQUAL TO 0.80

P01/P02	TOTAL EFFICIENCY	STATIC EFFICIENCY	N*SQRT(T01)/P01
1.06	0.8752	0.5117	0.600
1.24	0.9305	0.8431	0.800
1.39	0.9178	0.8662	0.900
1.49	0.9342	0.8829	0.950
1.60	0.9269	0.8705	0.980
1.64	0.9327	0.8709	1.000
1.69	0.9304	0.8626	1.010

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 1.00 P01/P02= 0.98

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1736.6	306.5	311.3	220.2	289.3	0.368	0.455	71.2	70.9	20.2	-67.4
3	1	1553.8	1780.5	1539.6	1740.9	177.3	319.1	170.9	291.6	0.303	0.457	0.0	76.2	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439	213	175

1	439.	213.	175.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 1.00 PO1/PO2= 1.19

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.9	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1765.4	306.5	310.4	220.2	269.0	0.368	0.430	71.2	70.9	20.2	-40.6
3	1	1553.8	1690.1	1539.6	1677.1	177.3	263.1	170.9	249.7	0.303	0.406	0.0	61.0	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	302.	265.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 1.00 PO1/PO2= 1.36

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1690.2	306.5	309.7	220.2	253.1	0.368	0.411	71.2	71.0	20.2	-15.2
3	1	1553.8	1646.7	1539.6	1631.1	177.3	229.1	170.9	220.5	0.303	0.369	0.0	45.3	-69.4	-69.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	356.	324.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 1.00 PO1/PO2= 1.49

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1665.8	306.5	309.2	220.2	242.6	0.368	0.398	71.2	71.0	20.2	-2.3
3	1	1553.8	1610.4	1539.6	1597.2	177.3	209.7	170.9	202.9	0.303	0.347	0.0	29.9	-69.4	-69.0

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	393.	367.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 1.00 PO1/PO2= 1.61

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1651.9	306.5	308.9	220.2	233.7	0.368	0.387	71.2	71.1	20.2	8.2
3	1	1553.8	1580.0	1539.6	1567.2	177.3	193.6	170.9	187.4	0.303	0.326	0.0	15.4	-69.4	-69.2

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	407.	402.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 1.00 PO1/PO2= 1.71 At Design Point

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1639.5	306.5	308.6	220.2	228.8	0.368	0.381	71.2	71.1	20.2	15.8
3	1	1553.8	1560.6	1539.6	1547.0	177.3	182.5	170.9	176.2	0.303	0.311	0.0	4.7	-69.4	-69.3

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439	427	428

from Cycle Calculation $V_{x_1} = V_{x_2} = V_{x_3} = 493$

1	439.	427.	428.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 1.00 PO1/PO2= 1.77

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1633.7	306.5	308.5	220.2	225.5	0.368	0.376	71.2	71.2	20.2	18.8
3	1	1553.8	1547.0	1539.6	1532.3	177.3	176.7	170.9	170.1	0.303	0.303	0.0	-2.1	-69.4	-69.3

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	436.	446.

FOR N/SQRT(TO1) EQUAL TO 1.00

PO1/PO2	TOTAL EFFICIENCY	STATIC EFFICIENCY	M*SQRT(TO1)/PO1
0.99	1.3733	-0.4296	0.600
1.19	0.9232	0.7128	0.800
1.36	0.9189	0.8223	0.900
1.49	0.9390	0.8709	0.950
1.61	0.9427	0.8861	0.980
1.71	0.9325	0.8792	1.000
1.77	0.9412	0.8862	1.010

At Design Point

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 1.10 PO1/PO2= 0.93

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1736.6	306.5	311.3	220.2	289.3	0.368	0.455	71.2	70.9	20.2	-71.2
3	1	1553.8	1804.7	1539.6	1751.0	177.3	336.9	170.9	298.5	0.303	0.465	0.0	78.4	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	213.	172.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 1.10 PO1/PO2= 1.14

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1705.4	306.5	310.4	220.2	269.0	0.368	0.430	71.2	70.9	20.2	-50.9
3	1	1553.8	1715.1	1539.6	1683.2	177.3	273.0	170.9	253.3	0.303	0.410	0.0	66.5	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	302.	262.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(TO1) = 1.10 PO1/PO2= 1.33

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1680.2	306.5	309.7	220.2	253.1	0.368	0.411	71.2	71.0	20.2	-30.5
3	1	1553.8	1656.8	1539.6	1634.4	177.3	235.7	170.9	223.1	0.303	0.373	0.0	54.4	-69.4	-68.9

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439	356	322

1	439.	356.	322.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 1.10 P01/P02= 1.46

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1665.8	306.5	309.2	220.2	242.6	0.368	0.398	71.2	71.0	20.2	-18.5
3	1	1553.8	1617.1	1539.6	1599.1	177.3	213.4	170.9	204.1	0.303	0.348	0.0	42.2	-69.4	-59.0

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	393.	365.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 1.10 P01/P02= 1.60

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1651.9	306.5	308.9	220.2	233.7	0.368	0.387	71.2	71.1	20.2	-7.6
3	1	1553.8	1582.6	1539.6	1566.9	177.3	195.4	170.9	187.8	0.303	0.327	0.0	29.3	-69.4	-69.2

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	407.	403.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 1.10 P01/P02= 1.70

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1639.5	306.5	308.6	220.2	226.8	0.368	0.381	71.2	71.1	20.2	1.1
3	1	1553.8	1560.7	1539.6	1545.4	177.3	183.6	170.9	176.6	0.303	0.312	0.0	19.2	-69.4	-69.3

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	427.	429.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE
CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 1.10 P01/P02= 1.78

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1633.7	306.5	308.5	220.2	225.5	0.368	0.376	71.2	71.2	20.2	4.7
3	1	1553.8	1544.6	1539.6	1529.2	177.3	175.7	170.9	168.7	0.303	0.301	0.0	11.6	-69.4	-69.4

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	436.	449.

FOR N/SQRT(T01) EQUAL TO 1.10

P01/P02	TOTAL EFFICIENCY	STATIC EFFICIENCY	M*SQRT(T01)/P01
0.93	1.1022	-1.8346	0.600
1.14	0.8002	0.5833	0.800
1.33	0.9023	0.7779	0.900
1.46	0.9381	0.8444	0.950
1.60	0.9466	0.8766	0.990
1.70	0.9422	0.8816	1.000
1.78	0.9419	0.8846	1.010

1	439.	356.	322.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 1.10 P01/P02= 1.46

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1665.8	306.5	309.2	220.2	242.6	0.368	0.398	71.2	71.0	20.2	-18.5
3	1	1553.8	1617.1	1539.6	1599.1	177.3	213.4	170.9	204.1	0.303	0.348	0.0	42.2	-69.4	-69.0

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	383.	365.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 1.10 P01/P02= 1.60

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1651.9	306.5	308.9	220.2	233.7	0.368	0.387	71.2	71.1	20.2	-7.6
3	1	1553.8	1562.6	1539.6	1556.9	177.3	195.4	170.9	187.8	0.303	0.327	0.0	29.3	-69.4	-69.2

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	407.	403.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 1.10 P01/P02= 1.70

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1639.5	306.5	308.6	220.2	226.8	0.368	0.381	71.2	71.1	20.2	1.1
3	1	1553.8	1560.7	1539.6	1545.4	177.3	183.6	170.9	176.6	0.303	0.312	0.0	19.2	-69.4	-69.3

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	427.	429.

FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE CALCULATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CACULATIONS AT DESIGN POINT
FOR N/SQRT(T01) = 1.10 P01/P02= 1.78

STATION	STAGE	TOTAL TEMPERATURE		STATIC TEMP(R)		TOTAL PRES(PSI)		STATIC PRES(PSI)		DENSITY(LB/FT**3)		ALPHA		BETA	
1	1	1767.8	1767.8	1753.6	1753.6	312.5	312.5	302.6	302.5	0.471	0.471	0.0	0.0	-68.0	0.0
2	1	1767.8	1767.8	1631.3	1633.7	306.5	308.5	220.2	225.5	0.368	0.376	71.2	71.2	20.2	4.7
3	1	1553.8	1544.6	1539.6	1529.2	177.3	175.7	170.9	168.7	0.303	0.301	0.0	11.6	-69.4	-69.4

STAGE	VX STATION 1	VX STATION 2	VX STATION 3
1	439.	436.	449.

FOR N/SQRT(T01) EQUAL TO 1.10

P01/P02	TOTAL EFFICIENCY	STATIC EFFICIENCY	N*SQRT(T01)/P01
0.93	1.1022	-1.8346	0.600
1.14	0.8092	0.5833	0.800
1.33	0.9223	0.7779	0.900
1.46	0.9381	0.8444	0.950
1.60	0.9466	0.8766	0.980
1.70	0.9422	0.8816	1.000
1.78	0.9419	0.8846	1.010

APPENDIX III

Computer Programs developed for the Design of a Free Vortex Axial Flow Turbine.

Computer Program 1 Complete design

Computer Program 2 Performance Calculations Only

COMPUTER PROGRAM #1

```
// ENDO,REGION=220K,CLASS=C
/*MITID USER=(M13582,214715,,,VME)
/*SRI LOW
/*MAIN TIME=6,LINES=2,CARDS=1
// EXEC WATFIV
//C.SYSIN DD *,DCB=BLKSIZE=2000
$JOB            ENDO,NOLIST,NOSUBCHK,TIME=60
      COMMON PI,GO,RJ,HJ,GAMMA,VX,SOMEGA,DHOS,CP,GAMMA2,GAMMA1,KK
      COMMON/AREA1/TET,TC,TIPCLA
      DIMENSION SPRES(3,3,12),RADIUS(3,3,12),ALPHA(3,3,12),BETA(3,3,12)
      DIMENSION DEN(3),RAD(3),TTEMP(3,12),TPRES(3,12),STEMP(3,3,12)
      DIMENSION REACT(3,3,12),RHO(3,3,12),RELMS(3,2,12),RELMR(3,2,12),T
     1TEMPR(3,2,12),VAXIAL(3,12)
      DIMENSION RBLADE(3,2,12),SBLADE(3,2,12),CHORDR(3,2,12),SIGMAB(2,12
     1),SIGMAC(12),BLADEH(2,12),PTOCHO(2,12),ASPECR(2,12),TEM(50),V(50)
      DIMENSION BLADWT(2,12),WTDISC(12),R(15),Z(15),NOBLAD(2,12)
      DIMENSION SPEED(5),WDOTP(7),OMEGAB(5),POIS(7),RHOC(3,10),BETAC(3,1
     10),ALPHAC(3,10),TOTC(3,10),TSC(3,10),POC(3,10),PSC(3,10),PPOC(3,10
     3),VEL(3,10),RVEL(3,10),RMAC(100),WTAP(100),PSPT(100),VELTOT(100),P
     101PO2(7),ENTMJ(7),ENSMJ(7),PTOC(3,10),A(6),B(6)
      DIMENSION WTAP11(70),WTAP12(70),RMAC11(70),RMAC12(70),VEOT11(70),V
     1EOT12(70),PSPT11(70),PSPT12(70)
      CHARACTER WORD*80
      DATA SPEED/.4,.6,.8,1.,1.1/
      DATA WDOTP/.6,.8,.9,.95,.98,1.,1.01/
      DATA B/1.6048,1.339,1.1857,1.1,1.04,1./
      DATA A/0.,.2,.4,.6,.8,1./
      LL=5
      KK=6
      E=.001
      HJ=778.16
      PI=3.14159264
      GO=32.174
      LKL=0
398   LKL=LKL+1
      READ(LL,217)WORD
```

```
217   FORMAT(A80)                                                    PGM10037
      WRITE(KK,218)WORD                                              PGM10038
218   FORMAT('1',A80)                                                PGM10039
      READ(LL,210)M1,M2,M,KLM,KTM,GAMMA,CP,POWER,W,TC,TET,TIPCLA,TOI,POI PGM10040
210   FORMAT(2I1,I3,2I5,2F5.3,F10.1,F10.2,3F5.2,2F10.1)              PGM10041
      READ(LL,211)PSI,RTE,RATIOT,REACTH,OMEGA,KLM1,M4,SPECWT,YMOD,C1,C2 PGM10042
211   FORMAT(4F5.3,F10.0,I2,I8,F5.3,F15.0,2F10.0)                    PGM10043
      READ(LL,212)ENI,RSHAFT,PRATIO,ULTSRE,ALPHAH,EMACH,M3,NKL,N,APEARA, PGM10044
     1TOO                                                            PGM10045
212   FORMAT(F5.3,F10.5,F5.3,F10.0,F5.3,F10.4,I1,I2,I2,F5.4,F5.2)    PGM10046
      POI=POI*144.                                                   PGM10047
      IF(M1.EQ.1)GO TO 214                                           PGM10048
      READ(LL,200) (RMAC(I),I=1,KLM)                                 PGM10049
       READ(LL,201) (WTAP(I),I=1,KLM)                                PGM10050
      READ(LL,201) (PSPT(I),I=1,KLM)                                 PGM10051
      READ(LL,201) (VELTOT(I),I=1,KLM)                               PGM10052
200   FORMAT(20F4.2)                                                 PGM10053
201   FORMAT(10F8.5)                                                 PGM10054
      READ(LL,227) (TEM(I),I=1,KTM)                                  PGM10055
      READ(LL,227) (V(I),I=1,KTM)                                    PGM10056
227   FORMAT(20F5.0)                                                 PGM10057
      KLM2=KLM-KLM1                                                  PGM10058
      DO 230 I=1,KLM1                                                PGM10059
      II=I+KLM1-1                                                    PGM10060
      RMAC11(I)=RMAC(I)                                              PGM10061
      WTAP11(I)=WTAP(I)                                              PGM10062
      PSPT11(I)=PSPT(I)                                              PGM10063
      VEOT11(I)=VELTOT(I)                                            PGM10064
      IF(I.GT.KLM2)GO TO 230                                         PGM10065
      RMAC12(I)=RMAC(II)                                             PGM10066
      WTAP12(I)=WTAP(II)                                             PGM10067
      PSPT12(I)=PSPT(II)                                             PGM10068
      VEOT12(I)=VELTOT(II)                                           PGM10069
230   CONTINUE                                                       PGM10070
214   SOMEGA=OMEGA*PI/30.                                            PGM10071
      GAMMA1=GAMMA/(GAMMA-1.)                                        PGM10072
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```
      LK=0                                                              PGM10109
      TTEMP(3,N)=TOE                                                    PGM10110
      TPRES(3,N)=PCE                                                    PGM10111
 5    PHI=VX/(SOMEGA*RHE)                                               PGM10112
      PSI=GO*HJ*DHCS/(SOMEGA*RHE)**2                                    PGM10113
      IF((PSI.GT.2.0).AND.(REACTH.LT.0.05))REACTH=0.05                  PGM10114
      ALPHAH=ATAN((1.-REACTH-PSI/2.)/PHI)                               PGM10115
      IF(PSI.LT.2.0)ALPHAH=0.0                                          PGM10116
      ALPHA(1,3,N)=ALPHAH                                               PGM10117
      ALPHA(2,3,N)=ANGLF(RHE,ALPHAH,RME)                                PGM10118
      ALPHA(3,3,N)=ANGLF(RHE,ALPHAH,RTE)                                PGM10119
      IF(EMACH.GT.0.0)GO TO 600                                         PGM10120
3     DO 4 I=1,3                                                        PGM10121
4     CALL TP1(TTEMP(3,N),STEMP(I,3,N),ALPHA(I,3,N),TPRES(3,N),SPRES(I,3PGM10122
     1,N),DEN(I))                                                       PGM10123
      RAD(1)=RHE                                                        PGM10124
      RAD(2)=RME                                                        PGM10125
      RAD(3)=RTE                                                        PGM10126
      CALL DENR(RAD,DEN,W,VXP)                                          PGM10127
      IF(ABS(VXP/VX-1.).LE.T)GO TO 6                                    PGM10128
      J=J+1                                                             PGM10129
      IF(J.GT.20)GO TO 6                                                PGM10130
      IF(VXP.GT.2.*VX)GO TO 656                                         PGM10131
      IF(J.EQ.2)GO TO 655                                               PGM10132
      IF(ABS(VXP/VX-1.).LT.0.1)GO TO 655                                PGM10133
      IF(VXP/VX.GT.1.)GO TO 654                                         PGM10134
      IF(LK.EQ.1)GO TO 657                                              PGM10135
      VX=VX-DELTAV                                                      PGM10136
      JK=1                                                              PGM10137
      LK=0                                                              PGM10138
      GO TO 5                                                           PGM10139
657   DELTAV=DELTAV/2.                                                  PGM10140
      VX=VX-DELTAV                                                      PGM10141
      JK=1                                                              PGM10142
      LK=0                                                              PGM10143
      GO TO 5                                                           PGM10144
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654   IF(JK.EQ.1)GO TO 658                                       PGM10145
      VX=VX+DELTAV                                               PGM10146
      LK=1                                                       PGM10147
      JK=0                                                       PGM10148
      GO TO 5                                                    PGM10149
658   DELTAV=DELTAV/2.                                           PGM10150
      VX=VX+DELTAV                                               PGM10151
      LK=1                                                       PGM10152
      JK=0                                                       PGM10153
      GO TO 5                                                    PGM10154
655   VX=VXP                                                     PGM10155
      GO TO 5                                                    PGM10156
656   VX=1.5*VX                                                  PGM10157
      J=1                                                        PGM10158
      GO TO 5                                                    PGM10159
659   H=0.9*(RTE-RHE)                                            PGM10160
      RMF=RTE-H/2.                                               PGM10161
      RHE=RTE-H                                                  PGM10162
      J=1                                                        PGM10163
      LK=0                                                       PGM10164
      JK=0                                                       PGM10165
      GO TO 5                                                    PGM10166
6     IF(EMACH.LT.0.0) VX=VXP                                    PGM10167
      IF(ABS(ALPHAH*180./PI).GT.25.)GO TO 659                    PGM10168
      KKK=N                                                      PGM10169
      DO 8 I=1,3                                                 PGM10170
      RADIUS(I,3,N)=RAD(I)                                       PGM10171
      RHO(I,3,N)=DEN(I)                                          PGM10172
      REACT(I,3,N)=REACTI(RADIUS(I,3,N),ALPHA(I,3,N))            PGM10173
8     BETA(I,3,N)=ANGLEB(ALPHA(I,3,N),RADIUS(I,3,N))             PGM10174
      GO TO 100                                                  PGM10175
600   J=0                                                        PGM10176
      VX=EMACH*SQRT((2./(GAMMA+1.))*GO*RJ*TOE)                   PGM10177
601   H=.98*RHE                                                  PGM10178
      DELTA=H/10.                                                PGM10179
      LK=0                                                       PGM10180
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      RJ=CP*HJ/GAMMA1                                                   PGM10073
      J=1                                                               PGM10074
      RHE=RTE/RATIOT                                                    PGM10075
      RME=(RTE+RHE)/2.                                                  PGM10076
      IF(M2.EQ.1)GO TO 215                                              PGM10077
      POWERB=POWER*550./HJ                                              PGM10078
      DHO=POWERB/(W*ENT)                                                PGM10079
      TOE=TOI-DHO/CP                                                    PGM10080
      TRATIO=TOE/TOI                                                    PGM10081
      ENP=ALOG(TRATIO)/ALOG((TRATIO-1.)/ENT+1.)                         PGM10082
      GAMMA2=GAMMA1/ENP                                                 PGM10083
      POE=POI*TRATIO**GAMMA2                                            PGM10084
      GO TO 216                                                         PGM10085
215   PRATIO=1./PRATIO                                                  PGM10086
      ENP=(ALOG(1.-ENT*(1.-PRATIO**(1./GAMMA1)))/ALOG(PRATIO))*GAMMA1   PGM10087
      GAMMA2=GAMMA1/ENP                                                 PGM10088
      TOE=TOI*PRATIO**(1./GAMMA2)                                       PGM10089
      DHO=CP*(TOI-TOE)                                                  PGM10090
      POWER=DHO*ENT*W*HJ/550.                                           PGM10091
      POE=POI*PRATIO                                                    PGM10092
216   UHE=SOMEGA*RHE                                                    PGM10093
      P01=POI/144.                                                      PGM10094
      P02=POE/144.                                                      PGM10095
      DHOS=PSI*(RHE*SOMEGA)**2/(GO*HJ)                                  PGM10096
      VX=.75*SOMEGA*RHE                                                 PGM10097
      DELTAV=VX/10.                                                     PGM10098
      IF(N.GT.0)GO TO 2                                                 PGM10099
      N=INT(DHO/DHOS)                                                   PGM10100
1     N=N+1                                                             PGM10101
2     RN=FLOAT(N)                                                       PGM10102
      DHOS=DHO/RN                                                       PGM10103
      IF((ALPHAH.EQ.0.0).AND.(PSI.LT.2.0))REACTH=1.-PSI/2.              PGM10104
      IF((REACTH.LT.0.05).AND.(ALPHAH.EQ.0.0))PSI=2.*(1.-0.05)          PGM10105
      IF((PSI.LT.2.0).AND.(ALPHAH.EQ.0.0))RHE=SQRT(DHOS*GO*HJ/(PSI*SOMEGPGM10106
     1A**2))                                                            PGM10107
      JK=0                                                              PGM10108
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      JK=0                                                              PGM10181
  603 J=J+1                                                             PGM10182
      RAD(1)=RHE                                                        PGM10183
      RAD(2)=RHE+H/2.                                                   PGM10184
      RAD(3)=RHE+H                                                      PGM10185
      IF(RAD(3)/RHE.GT.2.0)GO TO 602                                    PGM10186
      PSI=GO*HJ*DHOS/(SOMEGA*RAD(1))**2                                 PGM10187
      PHI=VX/(SOMEGA*RAD(1))                                            PGM10188
      IF((PSI.GT.2.0).AND.(REACTH.LT.0.05))REACTH=0.05                  PGM10189
      ALPHAH=ATAN((1.-REACTH-PSI/2.)/PHI)                               PGM10190
      IF(PSI.LT.2.)ALPHAH=0.0                                           PGM10191
      DO 611 I=1,3                                                      PGM10192
      ALPHA(I,3,N)=ANGLE(RAD(1),ALPHAH,RAD(I))                          PGM10193
  611 CALL TP1(TTEMP(3,N),STEMP(I,3,N),ALPHA(I,3,N),TPRES(3,N),SPRES(I,3PGM10194
     1,N),DEN(I))                                                       PGM10195
      CALL DENR(RAD,DEN,W,VXP)                                          PGM10196
      RME=RAD(2)                                                        PGM10197
      RHE=RAD(1)                                                        PGM10198
      RTE=RAD(3)                                                        PGM10199
      IF(ABS(VXP/VX-1.).LE.E)GO TO 6                                    PGM10200
      IF(J.GT.20)GO TO 6                                                PGM10201
      IF(VXP/VX.LT.1.)GO TO 604                                         PGM10202
      IF(LK.EQ.1)GO TO 607                                              PGM10203
      H=H+DELTA                                                         PGM10204
      JK=1                                                              PGM10205
      LK=0                                                              PGM10206
      IF(H.GT.0.5*RTE)VX=VXP                                            PGM10207
      GO TO 603                                                         PGM10208
  607 DELTA=DELTA/2.                                                    PGM10209
      H=H+DELTA                                                         PGM10210
      JK=1                                                              PGM10211
      LK=0                                                              PGM10212
      IF(H.GT.0.5*RTE)VX=VXP                                            PGM10213
      GO TO 603                                                         PGM10214
  604 IF(JK.EQ.1)GO TO 608                                              PGM10215
      H=H-DELTA                                                         PGM10216
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      LK=1                                                              PGM10217
      JK=0                                                              PGM10218
      GO TO 603                                                         PGM10219
 608  DELTA=DELTA/2.                                                    PGM10220
      H=H-DELTA                                                         PGM10221
      LK=1                                                              PGM10222
      JK=0                                                              PGM10223
      GO TO 603                                                         PGM10224
 602  RHE=RAD(3)/1.99                                                   PGM10225
      GO TO 601                                                         PGM10226
 100  J=3                                                               PGM10227
      K=J-2                                                             PGM10228
      TTEMP(K,N)=TTEMP(J,N)+DHOS/CP                                     PGM10229
      TPRES(K,N)=TPRES(J,N)/(TTEMP(J,N)/TTEMP(K,N))**GAMMA2             PGM10230
      RADIUS(M,K,N)=RADIUS(M,J,N)                                       PGM10231
      IF(N.EQ.1)GO TO 9                                                 PGM10232
      ALPHA(M,K,N)=ALPHA(M,J,N)                                         PGM10233
      GO TO 10                                                          PGM10234
 9    ALPHA(M,K,N)=0.0                                                  PGM10235
 10   BETA(M,K,N)=ANGLER(ALPHA(M,K,N),RADIUS(M,K,N))                    PGM10236
      CALL TP1(TTEMP(K,N),STEMP(M,K,N),ALPHA(M,K,N),TPRES(K,N),SPRES(M,KPGM10237
     1,N),DEN(M))                                                       PGM10238
      H=W/(2.*PI*VX*DEN(M)*RADIUS(M,K,N))                               PGM10239
      LK=0                                                              PGM10240
      JK=0                                                              PGM10241
      JJ=0                                                              PGM10242
      DELTA=H/10.                                                       PGM10243
 13   JJ=JJ+1                                                           PGM10244
      IF(M.EQ.1)GO TO 75                                                PGM10245
      IF(M.EQ.3)GO TO 76                                                PGM10246
      RAD(2)=RME                                                        PGM10247
      RAD(1)=RME-H/2.                                                   PGM10248
      RAD(3)=RME+H/2.                                                   PGM10249
      GO TO 77                                                          PGM10250
 75   RAD(1)=RHE                                                        PGM10251
      RAD(2)=RHE+H/2.                                                   PGM10252
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      RAD(3)=RHE+H                                                      PGM10253
      GO TO 77                                                          PGM10254
   76 RAD(3)=RTE                                                        PGM10255
      RAD(2)=RTE-H/2.                                                   PGM10256
      RAD(1)=RTE-H                                                      PGM10257
   77 DO 11 I=1,3                                                       PGM10258
      ALPHA(I,K,N)=ANGLE(RAD(M),ALPHA(M,K,N),RAD(I))                    PGM10259
   11 CALL IP1(TTEMP(K,N),STEMP(I,K,N),ALPHA(I,K,N),TPRES(K,N),SPRES(I,K,PGM10260
     1N),DEN(I))                                                        PGM10261
      CALL DENR(RAD,DEN,W,VXP)                                          PGM10262
      IF(ABS(VXP/VX-1.).LE.E)GO TO 15                                   PGM10263
      IF(JJ.EQ.20)GO TO 15                                              PGM10264
      IF(VXP/VX.LT.1.)GO TO 14                                          PGM10265
      IF(LK.EQ.1)GO TO 17                                               PGM10266
      H=H+DELTA                                                         PGM10267
      JK=1                                                              PGM10268
      LK=0                                                              PGM10269
      GO TO 13                                                          PGM10270
   17 DELTA=DELTA/2.                                                    PGM10271
      H=H+DELTA                                                         PGM10272
      JK=1                                                              PGM10273
      LK=0                                                              PGM10274
      GO TO 13                                                          PGM10275
   14 IF(JK.EQ.1)GO TO 18                                               PGM10276
      H=H-DELTA                                                         PGM10277
      LK=1                                                              PGM10278
      JK=0                                                              PGM10279
      GO TO 13                                                          PGM10280
   18 DELTA=DELTA/2.                                                    PGM10281
      H=H-DELTA                                                         PGM10282
      LK=1                                                              PGM10283
      JK=0                                                              PGM10284
      GO TO 13                                                          PGM10285
   15 DO 16 I=1,3                                                       PGM10286
      RHO(I,K,N)=DEN(I)                                                 PGM10287
      RADIUS(I,K,N)=RAD(I)                                              PGM10288
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```
      REACT(I,1,N)=REACTI(RADIUS(I,K,N),ALPHA(I,K,N))
16    BETA(I,K,N)=ANGLEB(ALPHA(I,K,N),RADIUS(I,K,N))
C SOLUTION FOR STATION 2
      ALPHA(M,2,N)=ANGLE2(RADIUS(M,3,N),ALPHA(M,3,N))
      TTEMP(2,N)=TTEMP(1,N)
      CALL TPD2(TTEMP(2,N),STEMP(M,1,N),STEMP(M,2,N),TPRES(2,N),SPRES(M,
     11,N),SPRES(M,2,N),ALPHA(M,2,N),DEN(M))
      H=W/(2.*PI*VX*DEN(M)*RADIUS(M,K,N))
      DELTA=H/10.
      JK=0
      LK=0
      JJ=0
33    JJ=JJ+1
      IF(M.EQ.1)GO TO 78
      IF(M.EQ.3)GO TO 79
      RAD(2)=RME
      RAD(1)=RAD(2)-H/2.
      RAD(3)=RAD(2)+H/2.
      GO TO 80
78    RAD(1)=RHE
      RAD(2)=RHE+H/2.
      RAD(3)=RHE+H
      GO TO 80
79    RAD(3)=RTE
      RAD(2)=RTE-H/2.
      RAD(1)=RTE-H
80    DO 25 I=1,3
      ALPHA(I,2,N)=ANGLE(RAD(M),ALPHA(M,2,N),RAD(I))
25    CALL TPD2(TTEMP(2,N),STEMP(I,1,N),STEMP(I,2,N),TPRES(2,N),SPRES(I,
     11,N),SPRES(I,2,N),ALPHA(I,2,N),DEN(I))
      CALL DENR(RAD,DEN,W,VXP)
      IF(ABS(VXP/VX-1.).LE.E)GO TO 30
      IF(VXP/VX.LT.1.)GO TO 34
      IF(JJ.EQ.20)GO TO 33
      IF(LK.EQ.1)GO TO 27
      H=H+DELTA
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      JK=1                                                              PGM10325
      LK=0                                                              PGM10326
      GO TO 33                                                          PGM10327
   27 DELTA=DELTA/2.                                                    PGM10328
      H=H+DELTA                                                         PGM10329
      JK=1                                                              PGM10330
      LK=0                                                              PGM10331
      GO TO 33                                                          PGM10332
   34 IF(JK.EQ.1)GO TO 38                                               PGM10333
      H=H-DELTA                                                         PGM10334
      LK=1                                                              PGM10335
      JK=0                                                              PGM10336
      GO TO 33                                                          PGM10337
   38 DELTA=DELTA/2.                                                    PGM10338
      H=H-DELTA                                                         PGM10339
      LK=1                                                              PGM10340
      JK=0                                                              PGM10341
      GO TO 33                                                          PGM10342
   30 DO 36 I=1,3                                                       PGM10343
      RHO(I,2,N)=DEN(I)                                                 PGM10344
      RADIUS(I,2,N)=RAD(I)                                              PGM10345
      REACT(I,2,N)=REACT2(RADIUS(I,2,N),ALPHA(I,2,N))                   PGM10346
   36 BETA(I,2,N)=ANGLEB(ALPHA(I,2,N),RADIUS(I,2,N))                    PGM10347
      IF(N.EQ.1)GO TO 40                                                PGM10348
      NN=N-1                                                            PGM10349
      DO 41 I=1,3                                                       PGM10350
      ALPHA(I,3,NN)=ALPHA(I,1,N)                                        PGM10351
      BETA(I,3,NN)=BETA(I,1,N)                                          PGM10352
      RADIUS(I,3,NN)=RADIUS(I,1,N)                                      PGM10353
      STEMP(I,3,NN)=STEMP(I,1,N)                                        PGM10354
      SPRES(I,3,NN)=SPRES(I,1,N)                                        PGM10355
   41 RHO(I,3,NN)=RHO(I,3,N)                                            PGM10356
      TTEMP(3,NN)=TTEMP(1,N)                                            PGM10357
      TPRES(3,NN)=TPRES(1,N)                                            PGM10358
      N=N-1                                                             PGM10359
      GO TO 100                                                         PGM10360
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40    WRITE(KK,43)W,POWER,TOI,TOE,P01,P02,ENT,ENP                             PGM10361
43    FORMAT('0','MASS FLOW(LB/S)   POWER(HP)   INLET TEMP(R)   EXIT TEMP(R PGM10362
     1)  INLET PRESS(PSI)  EXIT PRESS(PSI)  ISSEN EFFIC  POLY EFFIC'/' '   PGM10363
     1,F12.2,F12.0,2F14.0,F14.3,F17.3,F16.3,F12.3)                           PGM10364
      EMACH=VX/SQRT((2./(GAMMA+1.))*RJ*GO*TOE)                               PGM10365
      WRITE(KK,70)OMEGA,GAMMA,CP,REACTH,PSI,VX,EMACH                         PGM10366
70    FORMAT('0','OMEGA(RPM)  GAMMA  CP(BTU/LBMR)  REACTION HUB  PSI  VX   PGM10367
     1(FT/S)  CRIT MACH NO AT EXIT'/' ',F10.0,F7.3,F12.4,F14.3,F7.3,F11.  PGM10368
     11,F15.4)                                                               PGM10369
      DO 45 K=1,KKK                                                          PGM10370
      DO 45 J=1,3                                                            PGM10371
      DO 45 I=1,3                                                            PGM10372
      IF(J.EQ.3)GO TO 37                                                     PGM10373
      REALMS(I,J,K)=SQRT((TTEMP(J,K)/STEMP(I,J,K)-1.)*2./(GAMMA-1.))        PGM10374
      LJ=J+1                                                                 PGM10375
      TTEMPR(I,J,K)=STEMP(I,LJ,K)+(VX/COS(BETA(I,LJ,K)))**2/(2.*CP*HJ*GO   PGM10376
     1)                                                                      PGM10377
      RELMR(I,J,K)=SQRT((TTEMPR(I,J,K)/STEMP(I,LJ,K)-1.)*2./(GAMMA-1.))     PGM10378
37    CONTINUE                                                               PGM10379
      ALPHA(I,J,K)=180.*ALPHA(I,J,K)/PI                                      PGM10380
      BETA(I,J,K)=BETA(I,J,K)*180./PI                                        PGM10381
45    CONTINUE                                                               PGM10382
      WRITE(KK,42)                                                           PGM10383
42    FORMAT('0','LOCATION  STATION  STAGE  TOTAL TEMP  STATIC TEMP  TOT   PGM10384
     1AL PRESS  STATIC PRESS  DENSITY  ALPHA  BETA  REACTION  RADIUS')      PGM10385
      DO 250 K=1,KKK                                                         PGM10386
      DO 250 J=1,3                                                           PGM10387
      DO 250 I=1,3                                                           PGM10388
      IF((J.EQ.3).AND.(K.NE.KKK))GO TO 250                                   PGM10389
      TOTPRE=TPRES(J,K)/144.                                                 PGM10390
      STPRES=SPRES(I,J,K)/144.                                               PGM10391
      WRITE(KK,50)I,J,K,TTEMP(J,K),STEMP(I,J,K),TOTPRE,STPRES,RHO(I,J,K)   PGM10392
     1,ALPHA(I,J,K),BETA(I,J,K),REACT(I,J,K),RADIUS(I,J,K)                  PGM10393
50    FORMAT(' ',I5,I8,I8,F14.2,F12.2,F12.2,F12.2,4X,F9.4,F7.2,3X,F6.2,F    PGM10394
     18.3,F8.3)                                                              PGM10395
250   CONTINUE                                                               PGM10396
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      WRITE(KK,128)                                                     PGM10397
  128 FORMAT('0','LOCATION  STAGE  RELATIVE TOTAL TEMP FOR ROTOR  REAL M PGM10398
     1ACH NO FOR STATOR  RELATIVE MACH NO FOR ROTOR')                   PGM10399
      WRITE(KK,129)                                                     PGM10400
  129 FORMAT(' ',25X,'INLET',10X,'EXIT',7X,'INLET',10X,'EXIT',7X,'INLET',7X,'EX PGM10401
     1,10X,'EXIT')                                                      PGM10402
      WRITE(KK,130)((I,K,TTEMPR(I,1,K),TTEMPR(I,2,K),RFALMS(I,1,K),RFALM PGM10403
     1S(I,2,K),RELMR(I,1,K),RELMR(I,2,K),I=1,3),K=1,KKK)                PGM10404
  130 FORMAT(' ',I8,I7,F13.2,F16.2,4X,F10.4,F13.4,F12.4,F16.4)          PGM10405
C CALCULATE BLADE ANGLES OF STATOR AND ROTOR                            PGM10406
      DO 60 K=1,KKK                                                     PGM10407
      DO 60 J=1,2                                                       PGM10408
      DO 60 I=1,3                                                       PGM10409
      IF(J.EQ.2)GO TO 49                                                PGM10410
      RBLADE(I,J,K)=BETA(I,2,K)                                         PGM10411
      SBLADE(I,J,K)=ALPHA(I,J,K)                                        PGM10412
      GO TO 60                                                          PGM10413
   49 CALL BLADE(ALPHA(I,2,K),RFALMS(I,2,K),SBLADE(I,J,K),1)            PGM10414
      BETAOT=-BETA(I,3,K)                                               PGM10415
      CALL BLADE(BETAOT,RELMR(I,2,K),BLADE3,1)                          PGM10416
      RBLADE(I,2,K)=-BLADE3                                             PGM10417
   60 CONTINUE                                                          PGM10418
      WRITE(KK,145)                                                     PGM10419
  145 FORMAT('0','LOC  STAGE  STATOR ANGIN  GAS ANGIN  STATOR ANGOUT  GA PGM10420
     1S ANGOUT  ROTOR ANGIN  GAS ANGIN  ROTOR ANGOUT  GAS ANGOUT')      PGM10421
      WRITE(KK,150)((J,K,SBLADE(J,1,K),ALPHA(J,1,K),SBLADE(J,2,K),ALPHA( PGM10422
     1J,2,K),RBLADE(J,1,K),BETA(J,2,K),RBLADE(J,2,K),BETA(J,3,K),J=1,3), PGM10423
     2K=1,KKK)                                                          PGM10424
  150 FORMAT(' ',I2,I6,8F12.1)                                          PGM10425
      SIGMAT=.75*ULTSRF/1.2**2                                          PGM10426
      OMEGAT=SOMEGA                                                     PGM10427
      STRESC=0.0                                                        PGM10428
      TF=.49+.51*AREARA                                                 PGM10429
      CALL FIG(6,A,B,AREARA,CF)                                         PGM10430
      DO 103 K=1,KKK                                                    PGM10431
      DO 103 J=1,2                                                      PGM10432
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      L=J+1                                                              PGM10433
      HEIGHT=(RADIUS(3,I,K)-RADIUS(1,I,K)+RADIUS(3,J,K)-RADIUS(1,J,K))/2. PGM10434
     1.                                                                  PGM10435
      IF(J.EQ.1)GO TO 101                                                PGM10436
      SMTANG=RBLADE(1,1,K)-RBLADE(1,2,K)                                 PGM10437
      BETA3=-BETA(2,3,K)                                                 PGM10438
      CALL STOCRA(BETA(2,2,K),BETA3,PCRAT)                               PGM10439
      AREA=PI*(RADIUS(2,2,K)+RADIUS(2,3,K))*HEIGHT                       PGM10440
      STRESC=4.51*TF*SPECWT*AREA*144.*(OMEGA/1000.)**2                   PGM10441
      A2=PI*ALPHA(2,2,K)/180.                                            PGM10442
      A3=PI*ALPHA(2,3,K)/180.                                            PGM10443
      IF(J.EQ.2)GO TO 102                                                PGM10444
101   SMTANG=SBLADE(3,2,K)-SBLADE(3,1,K)                                 PGM10445
      A1=-ALPHA(2,1,K)                                                   PGM10446
      A2=ALPHA(2,2,K)                                                    PGM10447
      CALL STOCRA(A1,A2,PCRAT)                                           PGM10448
      A2=PI*A2/180.                                                      PGM10449
      A3=PI*A1/180.                                                      PGM10450
102   CALL SECMOD(SMTANG,TC,SM,AREAC2)                                   PGM10451
      STRESB=W*VX*(TAN(A2)-TAN(A3))*PCRAT*HEIGHT/(SM*2.*PI*(RADIUS(2,J,K PGM10452
     1)+RADIUS(2,L,K))*GO)                                               PGM10453
      FREQ=11.0*CF*SQRT(YMOD*SM*TC/(SPECWT*AREAC2))/(HEIGHT**2*144.)     PGM10454
      C4=1.3*41.*(OMEGA/60.)*STRESB/FREQ                                 PGM10455
      C5=C4/(C1*(1.-STRESC/C2))                                          PGM10456
      IF(J.EQ.1)C5=C4/C1                                                 PGM10457
      CHORD=C5**(1./3.)                                                  PGM10458
      FREQ1=FREQ*CHORD                                                   PGM10459
      HARMON=FREQ1/(OMEGA/60.)                                           PGM10460
      IF(CHORD.LT..6)CHORD=.6                                            PGM10461
      CK1=AREAC2*CHORD**2                                                PGM10462
      CK2=CK1*(1.-AREARA)                                                PGM10463
      CHORDR(2,J,K)=SQRT((CK1-CK2/2.)/AREAC2)                            PGM10464
      IF(J.EQ.1)GO TO 61                                                 PGM10465
      CHORDR(1,J,K)=CHORD                                                PGM10466
      CHORDR(3,J,K)=SQRT((CK1-CK2)/AREAC2)                               PGM10467
      GO TO 62                                                           PGM10468
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61    CHORDR(3,J,K)=CHORD                                        PGM10469
      CHORDR(1,J,K)=SQRT((CK1-CK2)/AREAC2)                       PGM10470
62    CONTINUE                                                   PGM10471
      SIGMAB(J,K)=STRESB/CHORD**2                                PGM10472
      BLADEH(J,K)=HEIGHT*12.                                     PGM10473
      ASPECR(J,K)=BLADEH(J,K)/CHORDR(2,J,K)                      PGM10474
      PTOCHO(J,K)=PCRAT                                          PGM10475
      IF(J.EQ.2) SIGMAC(K)=STRESC                                PGM10476
      PITCH=PCRAT*CHORDR(2,J,K)                                  PGM10477
      BLADNR=12.*PI*(RADIUS(2,J,K)+RADIUS(2,L,K))/PITCH          PGM10478
      KL=INT(BLADNR)                                             PGM10479
      IF(J.EQ.2)GO TO 63                                         PGM10480
      KL=(KL/2)*2                                                PGM10481
      GO TO 64                                                   PGM10482
63    CALL TESTP(KI,KL)                                          PGM10483
      IF(KI.EQ.1)GO TO 64                                        PGM10484
      KL=KL-1                                                    PGM10485
      GO TO 63                                                   PGM10486
64    NOBLAD(J,K)=KL                                             PGM10487
      PITCH=12.*PI*(RADIUS(2,J,K)+RADIUS(2,L,K))/FLOAT(KL)       PGM10488
      PTOCHO(J,K)=PITCH/CHORDR(2,J,K)                            PGM10489
      RHUB=(RADIUS(1,L,K)+RADIUS(1,J,K))/2.                      PGM10490
      RTIP=RHUB+HEIGHT                                           PGM10491
      ALPHAW=(1.-AREARA)/RTIP                                    PGM10492
      BLADWT(J,K)=12.*CK1*SPECWT*((ALPHAW/2.)*(RHUB**2-RTIP**2)+RTIP-RHU PGM10493
     1B)*FLOAT(NOBLAD(J,K))                                      PGM10494
      IF(J.EQ.1)GO TO 88                                         PGM10495
      WO=0.65*CHORDR(1,J,K)                                      PGM10496
      IF(WO.LT.0.7) WO=0.7                                       PGM10497
      IF(RSHAFT.LT.0.01) RSHAFT=RAD(M)/6.                        PGM10498
      RI=2.*RSHAFT                                               PGM10499
      TI=RSHAFT                                                  PGM10500
      TO=WO/24.                                                  PGM10501
      RO=RHUB-TO                                                 PGM10502
      ROPT=RO/RTIP                                               PGM10503
      RHRT=RHUB/RTIP                                             PGM10504
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      RIRT=RI/RTIP                                                      PGM10505
      SIGROW=12.*SPECWT*OMEGAT**2*RTIP**2/(SIGMAT*GO)                   PGM10506
      ALPPT=ALPHAW*RTIP                                                 PGM10507
      ABWOT=FLOAT(NOBLAD(J,K))*CK1/(WO*TO*12.)                          PGM10508
      CBLAD1=(1.-RHRT**2-(2.*ALPPT/3.)*(1.-RHRT**3))                    PGM10509
      CBLADE=(ABWOT/(4.*PI))*CBLAD1                                     PGM10510
      DELTAR=(RO-RI)/10.                                                PGM10511
      ZO=(WO*TO/RO)*((RORT**2+CBLADE)*SIGROW-1.)                        PGM10512
      IF(ZO.LT.WO/5.)ZO=WO/5.                                           PGM10513
      IF(ZO.LT.0.3)ZO=0.3                                               PGM10514
      ZI=ZO*EXP((SIGROW/2.)*(RORT**2-RIRT**2))                          PGM10515
      WI=(ZI*RI/TI)/(1.-RIRT**2*SIGROW)                                 PGM10516
      IF(WI.LT.1.2*WO)WI=1.2*WO                                         PGM10517
      WTMID=PI*SPECWT*288.*ZO*RTIP**2*EXP((SIGROW/2.)*RORT**2)*(EXP(-(SIPGM10518
     1GROW/2.)*RIRT**2)-EXP(-(SIGROW/2.)*RORT**2))/SIGROW               PGM10519
      WTIRIM=SPECWT*WI*PI*144.*(RI**2-RSHAFT**2)                        PGM10520
      WTORIM=SPECWT*WO*PI*144.*(RHUB**2-RO**2)                          PGM10521
      WTDISC(K)=WTIRIM+WTORIM+WTMID                                     PGM10522
      WTOT=WTDISC(K)+BLADWT(J,K)                                        PGM10523
      R(1)=RSHAFT                                                       PGM10524
      Z(1)=WI                                                           PGM10525
      R(2)=RI                                                           PGM10526
      Z(2)=WI                                                           PGM10527
      R(3)=RI                                                           PGM10528
      Z(3)=ZI                                                           PGM10529
      R(14)=RO                                                          PGM10530
      Z(14)=WO                                                          PGM10531
      R(15)=RHUB                                                        PGM10532
      Z(15)=WO                                                          PGM10533
      SUM=0.                                                            PGM10534
      SUM2=0.                                                           PGM10535
      DO 84 II=4,13                                                     PGM10536
      IJ=II-1                                                           PGM10537
      R(II)=R(IJ)+DELTAR                                                PGM10538
      Z(II)=ZO*EXP((SIGROW/2.)*(RORT**2-(R(II)/RTIP)**2))               PGM10539
      SUMZ=(Z(II)+Z(IJ))/2.                                             PGM10540
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      SUM=SUM+SUMZ*DELTAR                                               PGM10541
      SUM2=SUM2+SUMZ*((R(II)+R(IJ))/2.)**2*DELTAR                       PGM10542
 84   CONTINUE                                                          PGM10543
      AREADT=24.*(WO*TO+WI*TI+SUM)                                      PGM10544
      FORORI=WO*(RHUB**3-RC**3)                                         PGM10545
      FORIRI=WI*(RI**3-RSHAFT**3)                                       PGM10546
      FORMID=SUM2                                                       PGM10547
      FORCT=(SPECWT/GO)*(288.*(FORIRI/3.+FORORI/3.+FORMID)+FLOAT(NOBLAD(PGM10548
     1J,K))*RTIP**2*CK1*6.*CBLAD1/PI)                                   PGM10549
      BURST=FORCT/AREADT                                                PGM10550
      SPEEDB=SQRT(ULTSRE/BURST)*30./PI                                  PGM10551
      BSOS=SPEEDB/OMEGA                                                 PGM10552
 88   WRITE(KK,89)J,K,NOBLAD(J,K),BLADWT(J,K)                           PGM10553
 89   FORMAT('0','ROW  STAGE  NO BLADES  TOTAL BLADE WTS'/' ',I3,I7,I11,PGM10554
     1F10.2)                                                            PGM10555
      IF(J.EQ.1)GO TO 95                                                PGM10556
      WRITE(KK,121)J,K,CHORDR(1,J,K),CHORDR(2,J,K),CHORDR(3,J,K),BLADEH(PGM10557
     1J,K),FREQ1,HARMON,RTOCHO(J,K),ASPECR(J,K),SIGMAF(J,K),SIGMAC(K)   PGM10558
121   FORMAT('0','ROW  STAGE  CHORD1  CHORD2  CHORD3  HEIGHT  1-BEND FREPGM10559
     1Q  HARMONIC  R/C  H/C  BENDING STRESS  CENTRIFUGAL STRESS'/' ',I3,PGM10560
     3I7,4F8.3,F10.1,F10.1,F10.3,F6.3,F10.1,F17.1)                      PGM10561
      WRITE(KK,92)WTORIM,WTIRIM,WTMID,WTDISC(K),WTOT,RTIP,RHUB,SPEEDB,BSPGM10562
     1OS                                                                PGM10563
 92   FORMAT('0','WTORIM  WTIRIM  WTMID  WTDISC  WTOT  RTIP  RHUB  BURSTPGM10564
     1 SPEED  BS/OMEGA'//' ',F6.2,F8.2,F7.2,F8.2,F7.2,2F6.3,F10.0,F9.2) PGM10565
      DO 96 I=1,15                                                      PGM10566
 96   R(I)=R(I)*12.                                                     PGM10567
      WRITE(KK,97)                                                      PGM10568
 97   FORMAT('0','DISC DIMENSIONS FROM RSHAFT TO RHUB(INCHES)')         PGM10569
      WRITE(KK,93) (I,R(I),I,Z(I),I=1,15)                               PGM10570
 93   FORMAT(' ','R(',I2,') = ',F5.2,'  Z(',I2,') = ',F5.3)             PGM10571
      GO TO 98                                                          PGM10572
 95   WRITE(KK,120)J,K,CHORDR(1,J,K),CHORDR(2,J,K),CHORDR(3,J,K),BLADEH(PGM10573
     1J,K),FREQ1,HARMON,RTOCHO(J,K),ASPECR(J,K),SIGMAB(J,K)             PGM10574
120   FORMAT('0','ROW  STAGE  CHORD1  CHORD2  CHORD3  HEIGHT  1-BEND FREPGM10575
     1Q  HARMONIC  R/C  H/C  BENDING STRESS'/' ',I3,I7,4F8.3,2F10.1,F10.PGM10576
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      13,F6.3,F10.1)                                                    PGM10577
 98   CONTINUE                                                          PGM10578
 103  CONTINUE                                                          PGM10579
      WRITE(KK,403)                                                     PGM10580
 403  FORMAT(' ',' STAGE  STATION  DISTANCE FROM STATION 1, STAGE 1')   PGM10581
      J=1                                                               PGM10582
      K=1                                                               PGM10583
      SUM=0.0                                                           PGM10584
      WRITE(KK,402)K,J,SUM                                              PGM10585
 402  FORMAT(' ',I7,I8,F15.4)                                           PGM10586
 415  J=J+1                                                             PGM10587
      IF(J.EQ.1)J1=2                                                    PGM10588
      IF(J.EQ.2)J1=1                                                    PGM10589
      IF(J.EQ.1)K1=K-1                                                  PGM10590
      IF(J.EQ.2)K1=K                                                    PGM10591
      IF(J.EQ.1)J3=1                                                    PGM10592
      IF(J.EQ.2)J3=2                                                    PGM10593
      SUM=SUM+.11875*CHORDR(2,J1,K1)+1.1875*CHORDR(2,J,K)+.11875*CHORDR(PGM10594
     12,J3,K)                                                           PGM10595
      WRITE(KK,402)K,J,SUM                                              PGM10596
      IF((J.EQ.2).AND.(K.EQ.KKK))GO TO 401                              PGM10597
      IF(J.EQ.1)GO TO 415                                               PGM10598
      K=K+1                                                             PGM10599
      IF(J.EQ.2)J=0                                                     PGM10600
      GO TO 415                                                         PGM10601
 401  SUM=SUM+1.30625*CHORDR(2,2,KKK)+.11875*CHORDR(2,1,KKK)            PGM10602
      J=3                                                               PGM10603
      WRITE(KK,402)K,J,SUM                                              PGM10604
      WRITE(KK,404)                                                     PGM10605
 404  FORMAT('0',' LENGTH(IN)  RADHUBINLET(IN)  RADTIPINLET(IN)  RADHUBEPGM10606
     1XIT(IN)  RADTIPEXIT(IN)  WTOFSHAFT(LB)  WTOF DISCS+BLADES(LB)')   PGM10607
      RAD1H=RADIUS(1,1,1)*12.                                           PGM10608
      RAD1T=RADIUS(3,1,1)*12.                                           PGM10609
      RAD2H=RADIUS(1,3,KKK)*12.                                         PGM10610
      RAD2T=RADIUS(3,3,KKK)*12.                                         PGM10611
      SUM1=0.0                                                          PGM10612
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      SUM2=0.0                                                          PGM10613
      SHAFWT=SPECWT*PI*(RSHAFT*12.)**2*SUM                              PGM10614
      DO 410 K=1,KKK                                                    PGM10615
      DO 409 J=1,2                                                      PGM10616
409   SUM1=SUM1+BLADWT(J,K)                                             PGM10617
410   SUM2=SUM2+SUM1+WTDISC(K)                                          PGM10618
      WRITE(KK,405)SUM,RAD1H,RAD1T,RAD2H,RAD2T,SHAFWT,SUM2              PGM10619
405   FORMAT(' ',F9.2,F15.2,5F16.2)                                     PGM10620
      WRITE(7,779)CP,GO,HJ,RJ,VX,TOT,POT,E,W,KKK                        PGM10621
779   FORMAT(F5.3,F10.4,F8.3,F10.4,F10.1,F10.1,F10.3,F5.3,F10.3,I2)     PGM10622
      WRITE(7,780)GAMMA1,PI,SOMEGA,IET,TC,TIPCLA,GAMMA,KLM1,KLM           PGM10623
780   FORMAT(F10.5,F10.8,F10.3,4F5.3,I2,                                PGM10624
      WRITE(7,782)(((RADIUS(I,J,K),I=1,3),J=1,3),K=1,KKK)               PGM10625
782   FORMAT(8F10.4)                                                    PGM10626
      WRITE(7,781)((TTEMP(J,K),J=1,3),K=1,KKK)                          PGM10627
781   FORMAT(8F10.1)                                                    PGM10628
      WRITE(7,781)((STEMP(2,J,K),J=1,3),K=1,KKK)                        PGM10629
      WRITE(7,781)((TPRES(J,K),J=1,3),K=1,KKK)                          PGM10630
      WRITE(7,781)((SPRES(2,J,K),J=1,3),K=1,KKK)                        PGM10631
      WRITE(7,782)((RHO(2,J,K),J=1,3),K=1,KKK)                          PGM10632
      WRITE(7,782)((ALPHA(2,J,K),J=1,3),K=1,KKK)                        PGM10633
      WRITE(7,782)((BETA(2,J,K),J=1,3),K=1,KKK)                         PGM10634
      WRITE(7,782)((REALMS(2,J,K),J=1,2),K=1,KKK)                       PGM10635
      WRITE(7,782)((REIMR(2,J,K),J=1,2),K=1,KKK)                        PGM10636
      WRITE(7,782)((SBLADE(2,J,K),J=1,2),K=1,KKK)                       PGM10637
      WRITE(7,782)((RBLADE(2,J,K),J=1,2),K=1,KKK)                       PGM10638
      WRITE(7,782)((CHORDR(2,J,K),J=1,2),K=1,KKK)                       PGM10639
      WRITE(7,782)((ASPECR(J,K),J=1,2),K=1,KKK)                         PGM10640
      WRITE(7,782)((PTOCHO(J,K),J=1,2),K=1,KKK)                         PGM10641
      IF(M4.EQ.1)GO TO 399                                              PGM10642
      DO 350 MK=1,5                                                     PGM10643
      OMEGAB(MK)=SOMEGA*SPEED(MK)                                       PGM10644
      DO 350 MJ=1,7                                                     PGM10645
      K=1                                                               PGM10646
      BETAC(1,K)=0.0                                                    PGM10647
      ALPHAC(1,K)=0.0                                                   PGM10648
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      TOTC(1,K)=TOI                                                     PGM10649
      VAXIAL(1,K)=VX                                                    PGM10650
      TSC(1,K)=TOI-VX**2/(2.*CP*HJ*GO)                                  PGM10651
      POC(1,K)=POI                                                      PGM10652
      PSC(1,K)=POC(1,K)/(TOTC(1,K)/TSC(1,K))**GAMMA1                    PGM10653
      RHOC(1,K)=PSC(1,K)/(TSC(1,K)*RJ)                                  PGM10654
      PO1=POC(1,K)                                                      PGM10655
      TO1=TOI                                                           PGM10656
      GANG1=0.0                                                         PGM10657
  308 J=1                                                               PGM10658
  306 L=J+1                                                             PGM10659
      JJ=0                                                              PGM10660
      U=OMEGAB(MK)*RADIUS(2,L,K)                                        PGM10661
      RHO2=RHO(2,L,K)                                                   PGM10662
      RMAC2=.15*REALMS(2,2,K)                                           PGM10663
      IF(J.EQ.2)RMAC2=.15*RELMR(2,2,K)                                  PGM10664
      BLADE2=SBLADE(2,2,K)                                              PGM10665
      IF(J.EQ.2)BLADE2=RBLADE(2,2,K)                                    PGM10666
      ANNULA=PI*(RADIUS(3,L,K)**2-RADIUS(1,L,K)**2)                     PGM10667
  300 JJ=JJ+1                                                           PGM10668
      IF(J.EQ.2)BLADE2=-BLADE2                                          PGM10669
      CALL BLADE(GANG2,RMAC2,BLADE2,2)                                  PGM10670
      IF(J.EQ.2)GANG2=-GANG2                                            PGM10671
      IF(J.EQ.2)BLADE2=-BLADE2                                          PGM10672
      CALL FIG(KLM,RMAC,VELTOT,RMAC2,VETOT2)                            PGM10673
      V2=SQRT(TO1)*VETOT2                                               PGM10674
      CALL FIG(KLM,RMAC,PSPT,RMAC2,PSPT2)                               PGM10675
      T2=TO1*PSPT2**(1./GAMMA1)                                         PGM10676
      IF(PSPT2.LT.0.0)GO TO 399                                         PGM10677
      BLADE1=SBLADE(2,1,K)                                              PGM10678
      IF(J.EQ.2)BLADE1=RBLADE(2,1,K)                                    PGM10679
      IF(J.EQ.1)KLEAR=1                                                 PGM10680
      IF(J.EQ.2)KLEAR=3                                                 PGM10681
      IF((J.EQ.2).AND.(M3.EQ.1))KLEAR=2                                 PGM10682
      CALL PLOSS(GANG1,GANG2,RHO2,T2,BLADE1,PTOCHO(J,K),ASPECR(J,K),RMACPGM10683
     12,V2,CHORDR(2,J,K),J,K,KLEAR,YT,KTM,TEM,V)                        PGM10684
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      PO2=PO1/(YT*(1.-PSPT2)+1.)
      O2=WDOTP(MJ)*W*SQRT(TO1)/(ANNULA*COS(GANG2*PI/180.)*PO2)
      IF(O2.GT.WTAP(KLM1))O2=WTAP(KLM1)*.99
      IF(RMAC2.GT.RMAC(KLM1))GO TO 316
      CALL FIG(KLM1,WTAP11,RMAC11,O2,RMAC2P)
      CALL FIG(KLM1,WTAP11,VEOT11,O2,VETOT2)
      CALL FIG(KLM1,WTAP11,PSPT11,O2,PSPT2)
      GO TO 317
316   CALL FIG(KLM2,WTAP12,RMAC12,O2,RMAC2P)
      CALL FIG(KLM2,WTAP12,VEOT12,O2,VETOT2)
      CALL FIG(KLM2,WTAP12,PSPT12,O2,PSPT2)
317   PO2=PO1/(YT*(1.-PSPT2)+1.)
      P2=PO2*PSPT2
      T2=TO1*PSPT2**(1./GAMMA1)
      RHO2=P2/(T2*RJ)
      V2=SQRT(TO1)*VETOT2
      IF(ABS(RMAC2P/RMAC2-1.).LE.E)GO TO 302
      IF((RMAC2P.GT.0.9).AND.(JJ.GT.3))GO TO 304
315   IF(JJ.EQ.10)GO TO 302
      IF(ABS(RMAC2P/RMAC2-1.).LT.0.03)GO TO 318
      RMAC2=RMAC2P
      GO TO 300
318   RMAC2=RMAC2+(RMAC2P-RMAC2)/2.
      GO TO 300
304   O2PRIM=1.0001*O2
      IF((RMACP.GT.1.0))GO TO 330
      CALL FIG(KLM1,WTAP11,PSPT11,O2PRIM,PSPTR)
      GO TO 331
330   CALL FIG(KLM2,WTAP12,PSPT12,O2PRIM,PSPTR)
331   PO2PO1=1./(YT*(1.-PSPTR)+1.)
      WPRIME=O2PRIM*PO2PO1*ANNULA*COS(GANG2*PI/180.)*PO1/SQRT(TO1)
      IF(WPRIME.LT.W*WDOTP(MJ))GO TO 305
      GO TO 315
305   WRITE(KK,310)J,K,SPEED(MK),POT/144.
310   FORMAT(' ','ROW',I2,' IN STAGE',I3,' FOR N/SQRT(TO1) = ',F4.1,' FO
     1R PO1 = ',F8.1,' CHOKED')
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      CALL FIG(KLM2,WTAP12,PSPT12,Q2,PSPT2)                             PGM10721
      CALL FIG(KLM2,WTAP12,VEOT12,Q2,VETOT2)                            PGM10722
      V2=SQRT(TO1)*VETOT2                                               PGM10723
      PO2=PO1/(YT*(1.-PSPT2)+1.)                                        PGM10724
      P2=PO2*PSPT2                                                      PGM10725
      T2=TO1*PSPT2**(1./GAMMA1)                                         PGM10726
      RHO2=P2/(T2*PJ)                                                   PGM10727
      GANG2=ARCOS(W*WDOTP(MJ)*SQRT(TO1)/(PO2*Q2*ANNULA))*180./PI        PGM10728
  302 IF(J.EQ.2)GO TO 307                                               PGM10729
      J=J+1                                                             PGM10730
      ALPHAC(2,K)=GANG2                                                 PGM10731
      BETAC(2,K)=(ATAN(TAN(GANG2*PI/180.)-U/(V2*COS(GANG2*PI/180.))))*18PGM10732
     10./PI                                                             PGM10733
      RHOC(2,K)=RHO2                                                    PGM10734
      VWSQ=(V2*COS(GANG2*PI/180.))**2*(1.+(TAN(BETAC(2,K)*PI/180.))**2) PGM10735
      VAXIAL(2,K)=V2*COS(GANG2*PI/180.)                                 PGM10736
      TOTC(2,K)=TO1                                                     PGM10737
      TSC(2,K)=TO1-V2**2/(2.*CP*HJ*GO)                                  PGM10738
      TO1=T2+VWSQ/(2.*CP*HJ*GO)                                         PGM10739
      PSC(2,K)=P2                                                       PGM10740
      POC(2,K)=PO2                                                      PGM10741
      RVTOTR=SQRT(VWSQ)/SQRT(TO1)                                       PGM10742
      CALL FIG(KLM,VELTOT,PSPT,RVTOTR,PSPT2)                            PGM10743
      PO1=P2/PSPT2                                                      PGM10744
      GANG1=BETAC(2,K)                                                  PGM10745
      GO TO 306                                                         PGM10746
  307 TSC(3,K)=TO1-V2**2/(2.*GO*HJ*CP)                                  PGM10747
      VAXIAL(3,K)=V2*COS(GANG2*PI/180.)                                 PGM10748
      PSC(3,K)=PO2*PSPT2                                                PGM10749
      RHOC(3,K)=RHO2                                                    PGM10750
      BETAC(3,K)=GANG2                                                  PGM10751
      U=OMEGAB(MK)*RADIUS(2,3,K)                                        PGM10752
      ALPHAC(3,K)=(ATAN(TAN(GANG2*PI/180.)+U/(V2*COS(GANG2*PI/180.))))*1PGM10753
     180./PI                                                            PGM10754
      VELSQ=(V2*COS(GANG2*PI/180.))**2*(1.+TAN(ALPHAC(3,K)*PI/180.)**2) PGM10755
      TOTC(3,K)=TSC(3,K)+VELSQ/(2.*GO*HJ*CP)                            PGM10756
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```
      POC(3,K)=PSC(3,K)*(TOTC(3,K)/TSC(3,K))**GAMMA1                    PGM10757
      IF(K.EQ.KKK)GO TO 309                                             PGM10758
      L=K                                                               PGM10759
      K=K+1                                                             PGM10760
      ALPHAC(1,K)=ALPHAC(3,L)                                           PGM10761
      VAXIAL(1,K)=VAXIAL(3,L)                                           PGM10762
      BETAC(1,K)=BETAC(3,L)                                             PGM10763
      TSC(1,K)=TSC(3,L)                                                 PGM10764
      POC(1,K)=POC(3,L)                                                 PGM10765
      PSC(1,K)=PSC(3,L)                                                 PGM10766
      TOTC(1,K)=TOTC(3,L)                                               PGM10767
      RHOC(1,K)=RHOC(3,L)                                               PGM10768
      GANG1=ALPHAC(1,K)                                                 PGM10769
      TO1=TOTC(1,K)                                                     PGM10770
      PO1=POC(1,K)                                                      PGM10771
      GO TO 308                                                         PGM10772
  309 PO1PO2(MJ)=PCI/POC(3,KKK)                                         PGM10773
      ENTMJ(MJ)=(TOTC(1,1)-TOTC(3,KKK))/(TOTC(1,1)*(1.-(POC(3,KKK)/POC(1PGM10774
     1,1))**(1./GAMMA1)))                                               PGM10775
      ENSMJ(MJ)=(TOTC(1,1)-TOTC(3,KKK))/(TOTC(1,1)*(1.-(PSC(3,KKK)/POC(1PGM10776
     1,1))**(1./GAMMA1)))                                               PGM10777
      WRITE(KK,311)SPEED(MK),PO1PO2(MJ)                                 PGM10778
  311 FORMAT('0','FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF PGM10779
     1 CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE'/' ','CALCUL PGM10780
     2ATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CAL PGM10781
     3CULATIONS AT DESIGN POINT'/' ','FOR N/SQRT(TO1)=',F5.2,' PO1/PO2='PGM10782
     3,F5.2)                                                            PGM10783
      WRITE(KK,312)                                                     PGM10784
  312 FORMAT('0','STATION  STAGE  TOTAL TEMPERATURE  STATIC TEMP(R)  TOTPGM10785
     1AL PRES(PSI)  STATIC PRES(PSI)  DENSITY(LB/FT**3)  ALPHA    BETA')PGM10786
  313 FORMAT(' ',I4,I8,F11.1,F8.1,F10.1,F8.1,F9.1,F7.1,F9.1,F7.1,6X,2F6.PGM10787
     13,4F6.1)                                                          PGM10788
      DO 320 K1=1,KKK                                                   PGM10789
      DO 320 J1=1,3                                                     PGM10790
      TPRES2=TPRES(J1,K1)/144.                                          PGM10791
      TPRESC=POC(J1,K1)/144.                                            PGM10792
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      SPRES2=SPRES(2,J1,K1)/144.                                        PGM10793
      SPRESC=PSC(J1,K1)/144.                                            PGM10794
      IF((J1.EQ.3).AND.(K1.NE.KKK))GO TO 320                            PGM10795
      WRITE(KK,313)J1,K1,TTEMP(J1,K1),TOTC(J1,K1),STEMP(2,J1,K1),TSC(J1,PGM10796
     1K1),TPRES2,TPRESC,SPRES2,SPRESC,RHO(2,J1,K1),RHOC(J1,K1),ALPHA(2,JPGM10797
     11,K1),ALPHAC(J1,K1),BETA(2,J1,K1),BETAC(J1,K1)                    PGM10798
  320 CONTINUE                                                          PGM10799
      WRITE(KK,345)                                                     PGM10800
  345 FORMAT(' ','STAGE  VX STATION 1  VX STATION 2  VX STATION 3')     PGM10801
      WRITE(KK,344)(K1,(VAXIAL(J1,K1),J1=1,3),K1=1,KKK)                 PGM10802
  344 FORMAT(' ',I4,3F13.0)                                             PGM10803
      IF(MJ.NE.7)GO TO 350                                              PGM10804
      WRITE(KK,326)SPEED(MK)                                            PGM10805
  326 FORMAT('0','FOR N/SQRT(TC1) EQUAL TO ',F5.2)                      PGM10806
      WRITE(KK,328)                                                     PGM10807
  328 FORMAT('0',' PO1/PO2  TOTAL EFFICIENCY  STATIC EFFICIENCY  M*SQRT(PGM10808
     1TO1)/PO1')                                                        PGM10809
      WRITE(KK,327)(PO1PO2(I),ENTMJ(I),ENSMJ(I),WDOTP(I),I=1,7)         PGM10810
  327 FORMAT(' ',F7.2,F15.4,F18.4,F17.3)                                PGM10811
  350 CONTINUE                                                          PGM10812
  399 CONTINUE                                                          PGM10813
      IF(LKL.NE.NKL)GO TO 398                                           PGM10814
      STOP                                                              PGM10815
      END                                                               PGM10816
      SUBROUTINE PLOSS(ANGIN,ANGOUT,RHO,TEMP,BLADIN,PITCHO,ASPECR,REMACHPGM10817
     1,VELOT,CHORD,J,K,KLEAR,YT,KTM,TFM,U)                              PGM10818
      COMMON PI,GO,RJ,HJ,GAMMA,VX,SOMEGA,DHOS,CP,GAMMA2,GAMMA1,KK       PGM10819
      COMMON/AREA1/TFT,TC,TIPCLA                                        PGM10820
      DIMENSION B180(9),B275(9),A3(9),B370(9),B365(9),B360(9),B350(9),B3PGM10821
     140(9),A5(5),B5(5),A15(5),B1540(5),B1550(5),B1560(5),B1570(5),A7(7)PGM10822
     1,B7(7),A811(11),B865(11),B860(11),B855(11),B850(11),B840(11),A8(9)PGM10823
     3,B830(9),PCA(7),PCB(7),YP2A(7),YP2B(7),TEX(7),TEY(7),ANG80(7),ANG7PGM10824
     40(6),ANG30(7),YPIA(6),YPNA(7),SI75(7),ANG47(4),SIDA(4),AI(9),TFM(KPGM10825
     5TM),U(KTM),BI70(9),BI65(9),BI60(9),BI55(9),BI50(9),BI40(9)        PGM10826
      DATA A3/.3,.4,.5,.6,.7,.8,.9,1.,1.1/                              PGM10827
      DATA B180/.07149,.06468,.0594,.05889,.06128,.06553,.07285,.0834,.0PGM10828
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      19532/                                                          PGM10829
      DATA B275/.06979,.05872,.05021,.04766,.04817,.05140,.05651,.06383,PGM10830
     1.074/                                                           PGM10831
      DATA B370/.06894,.05532,.04511,.03966,.03830,.04,.0434,.04936,.057PGM10832
     187/                                                             PGM10833
      DATA B365/.06809,.05498,.04255,.03574,.03098,.02928,.03115,.03643,PGM10834
     1.04494/                                                         PGM10835
      DATA B360/.06638,.05362,.04068,.03149,.02689,.02417,.02451,.02809,PGM10836
     1.03404/                                                         PGM10837
      DATA B350/.06519,.05055,.03949,.0303,.02502,.02264,.02128,.02077,.PGM10838
     102247/                                                          PGM10839
      DATA B340/.06468,.0497,.03745,.02911,.02383,.02043,.01855,.01804,.PGM10840
     101872/                                                          PGM10841
      DATA AI/.3,.4,.5,.6,.7,.8,.9,1.,1.1/                            PGM10842
      DATA BI70/.16113,.14186,.13640,.13981,.14868,.16198,.17596,.19096,PGM10843
     1.2077/                                                          PGM10844
      DATA BI65/.15613,.13026,.11867,.11628,.12089,.12907,.13981,.15192,PGM10845
     1.1668/                                                          PGM10846
      DATA BI60/.14834,.11799,.10571,.10196,.10401,.10827,.11475,.12361,PGM10847
     1.1328/                                                          PGM10848
      DATA BI55/.14749,.11509,.09787,.08747,.08491,.08730,.09378,.10315,PGM10849
     1.1166/                                                          PGM10850
      DATA BI50/.14408,.11168,.09122,.07843,.0731,.07502,.0798,.08781,.0PGM10851
     1987/                                                            PGM10852
      DATA BI40/.13981,.10656,.0861,.07315,.06591,.0653,.0682,.07398,.08PGM10853
     1/                                                               PGM10854
      DATA A5/.4,.5,.6,.7,.8/                                         PGM10855
      DATA B5/8.0576,6.8921,4.6043,1.4532,-2.3022/                    PGM10856
      DATA A15/.8,.85,.9,.95,1./                                      PGM10857
      DATA B1540/-2.3022,-3.3813,-4.6763,-5.5396,-6.4023/             PGM10858
      DATA B1550/-2.3044,-4.4604,-6.6187,-8.9928,-11.3669/            PGM10859
      DATA B1560/-2.3066,-4.7626,-8.0432,-11.3669,-14.777/            PGM10860
      DATA B1570/-2.3088,-5.3237,-9.6403,-14.1726,-19.1367/           PGM10861
      DATA A7/-.9,-.6,-.4,-.2,0.,.2,.4/                               PGM10862
      DATA B7/11.218,25.671,33.437,40.988,44.223,43.576,40.34/        PGM10863
      DATA A811/-.9,-.8,-.6,-.4,-.2,0.,.2,.4,.6,.8,1./                PGM10864
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      DATA B865/10.355,14.453,21.788,28.562,34.30,37.105,37.105,34.732,3PGM10865
     10.503,24.808,19.199/                                              PGM10866
      DATA B860/8.025,11.563,17.397,22.435,26.318,28.993,30.547,29.899,2PGM10867
     17.57,23.384,19.199/                                               PGM10868
      DATA B855/7.982,10.01,14.324,17.905,21.141,23.643,25.283,25.369,24PGM10869
     1.032,21.788,19.1990/                                              PGM10870
      DATA B850/7.162,8.802,11.735,14.367,16.611,18.532,19.976,20.882,20PGM10871
     1.796,20.192,19.631/                                               PGM10872
      DATA B840/6.04,6.903,8.845,10.355,11.865,13.289,14.626,15.532,16.4PGM10873
     181,17.56,18.984/                                                  PGM10874
      DATA A8/-.9,-.8,-.6,-.4,-.2,0.0,.2,.4,.6/                         PGM10875
      DATA B830/4.099,5.177,6.472,7.55,8.629,9.406,10.268,10.786,11.045/PGM10876
      DATA PCA/.4,.5,.6,.7,.8,.9,1./                                    PGM10877
      DATA PCB/1.1069,1.0784,1.0483,1.0155,.9807,.9405,.9/              PGM10878
      DATA YP2A/-4.,-3.,-2.,-1.,0.,1.,1.5/                              PGM10879
      DATA YP2B/6.1573,4.2565,2.7395,1.5663,1.,2.0922,4.5599/           PGM10880
      DATA TEX/0.,.02,.04,.06,.08,.1,.12/                               PGM10881
      DATA TEY/.91304,1.,1.1087,1.239,1.3826,1.5304,1.6913/             PGM10882
      DATA ANG80/40.,50.,60.,65.,70.,75.,80./                           PGM10883
      DATA ANG70/40.,50.,55.,60.,65.,70./                               PGM10884
      DATA ANG47/40.,50.,60.,70./                                       PGM10885
      DATA ANG30/30.,40.,50.,55.,60.,65.,70./                           PGM10886
      U1=U(KTM)                                                         PGM10887
      IF(TEMP.GT.TFM(KTM))GO TO 1                                       PGM10888
      CALL FIG(KTM,TFM,U,TEMP,U1)                                       PGM10889
    1 RE=((RHO*CHORD*VELOT)/(U1*12.))*1.E7                              PGM10890
      YPI=0.0                                                           PGM10891
      A1=ANGIN                                                          PGM10892
      IF(J.EQ.1)A1=-ANGIN                                               PGM10893
      A2=ANGOUT                                                         PGM10894
      IF(J.EQ.2)A2=-ANGOUT                                              PGM10895
      B1=BLADIN*PI/180.                                                 PGM10896
      CINCI=ANGIN-BLADIN                                                PGM10897
      IF(J.EQ.1)CINCI=BLADIN-ANGIN                                      PGM10898
      IF((PTOCHO.LT.0.4).OR.(PTOCHO.GT.1.1))GO TO 25                    PGM10899
      IF((ABS(ANGOUT).GT.80.).OR.(ABS(ANGOUT).LT.30.))GO TO 25          PGM10900
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      IF(ABS(BLADIN).LT.0.5)GO TO 6                                     PGM10901
      IF(ABS(ANGOUT).GT.70.)GO TO 2                                     PGM10902
      IF(ABS(ANGOUT).LT.40.)GO TO 4                                     PGM10903
      CALL FIG(9,AI,BI40,PTOCHO,YPIA(1))                                PGM10904
      CALL FIG(9,AI,BI50,PTOCHO,YPIA(2))                                PGM10905
      CALL FIG(9,AI,BI55,PTOCHO,YPIA(3))                                PGM10906
      CALL FIG(9,AI,BI60,PTOCHO,YPIA(4))                                PGM10907
      CALL FIG(9,AI,BI65,PTOCHO,YPIA(5))                                PGM10908
      CALL FIG(9,AI,BI70,PTOCHO,YPIA(6))                                PGM10909
      CALL FIG(6,ANG70,YPIA,A2,YPI)                                     PGM10910
      GO TO 6                                                           PGM10911
2     WRITE(KK,3)J,K                                                    PGM10912
3     FORMAT(' ','THE ANGLE OUT WAS GREATER THAN 70 DEG AND THE DATA WAS PGM10913
     1 FROM 70 DEG FOR ROW',I3,'STAGE',I3)                              PGM10914
      GO TO 6                                                           PGM10915
4     WRITE(KK,5)J,K                                                    PGM10916
5     FORMAT(' ','THE ANGLE OUT WAS LESS    THAN 40 DEG AND THE DATA WAS PGM10917
     1 FROM 40 DEG FOR ROW',I3,'STAGE',I3)                              PGM10918
      CALL FIG(9,AI,BI40,PTOCHO,YPI)                                    PGM10919
6     IF(ABS(ANGOUT).LT.40.)GO TO 7                                     PGM10920
      CALL FIG(9,A3,B340,PTOCHO,YPNA(1))                                PGM10921
      CALL FIG(9,A3,B350,PTOCHO,YPNA(2))                                PGM10922
      CALL FIG(9,A3,B360,PTOCHO,YPNA(3))                                PGM10923
      CALL FIG(9,A3,B365,PTOCHO,YPNA(4))                                PGM10924
      CALL FIG(9,A3,B370,PTOCHO,YPNA(5))                                PGM10925
      CALL FIG(9,A3,B375,PTOCHO,YPNA(6))                                PGM10926
      CALL FIG(9,A3,B380,PTOCHO,YPNA(7))                                PGM10927
      CALL FIG(7,ANG80,YPNA,A2,YPN)                                     PGM10928
      GO TO 8                                                           PGM10929
7     WRITE(KK,5)J,K                                                    PGM10930
      CALL FIG(9,A3,B340,PTOCHO,YPN)                                    PGM10931
8     YP=(YPN+(BLADIN/ANGOUT)**2*(YPI-YPN))*(PC/.2)**(-BLADIN/ANGOUT)   PGM10932
      IF(ABS(CINCI).LT.0.5)GO TO 18                                     PGM10933
      IF(PTOCHO.GT.1.)GO TO 35                                          PGM10934
      CALL FIG(7,PCA,PCB,PTOCHO,C75)                                    PGM10935
      GO TO 34                                                          PGM10936
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35    C75=PCB(7)-.4*(PTOCHO-1.)                                    PGM10937
34    A275=A2/C75                                                   PGM10938
      AB=BLADIN/A275                                                PGM10939
      IF(J.EQ.2)AB=-BLADIN/A275                                     PGM10940
      IF((AB.LT.-.9).OR.(AB.GT.1.))GO TO 25                         PGM10941
      IF((A275.GT.65.).AND.(AB.GT.0.4))GO TO 9                      PGM10942
      IF((A275.LT.40.).AND.(AB.GT.0.6))GO TO 11                     PGM10943
      CALL FIG(9,A8,B830,AB,SI75(1))                                PGM10944
      CALL FIG(11,A811,B840,AB,SI75(2))                             PGM10945
      CALL FIG(11,A811,B850,AB,SI75(3))                             PGM10946
      CALL FIG(11,A811,B855,AB,SI75(4))                             PGM10947
      CALL FIG(11,A811,B860,AB,SI75(5))                             PGM10948
      CALL FIG(11,A811,B865,AB,SI75(6))                             PGM10949
      CALL FIG(7,A7,B7,AB,SI75(7))                                  PGM10950
      CALL FIG(7,ANG30,SI75,A275,SI751)                             PGM10951
      GO TO 12                                                      PGM10952
9     WRITE(KK,10)J,K                                               PGM10953
10    FORMAT(' ','THE ANGLE OUT WAS GREATER THAN 65 DEG AND THE DATA WAS    PGM10954
     1 FROM 65 DEG FOR ROW',I3,'STAGE',I3)                          PGM10955
      CALL FIG(11,A811,B865,AB,SI751)                               PGM10956
      GO TO 12                                                      PGM10957
11    WRITE(KK,5)J,K                                                PGM10958
      CALL FIG(9,A8,B830,AB,SI751)                                  PGM10959
12    IF(PTOCHO.GT.0.8)GO TO 13                                     PGM10960
      CALL FIG(5,A5,B5,PTOCHO,DELTSI)                               PGM10961
      GO TO 16                                                      PGM10962
13    IF(PTOCHO.GT.1.)GO TO 14                                      PGM10963
      IF((A2.LT.40.).OR.(A2.GT.70.))GO TO 14                        PGM10964
      CALL FIG(5,A15,B1540,PTOCHO,SIDA(1))                          PGM10965
      CALL FIG(5,A15,B1550,PTOCHO,SIDA(2))                          PGM10966
      CALL FIG(5,A15,B1560,PTOCHO,SIDA(3))                          PGM10967
      CALL FIG(5,A15,B1570,PTOCHO,SIDA(4))                          PGM10968
      CALL FIG(4,ANG47,SIDA,A2,DELTSI)                              PGM10969
      GO TO 16                                                      PGM10970
14    WRITE(KK,15)J,K                                               PGM10971
15    FORMAT(' ','THE P/C RATIO WAS GREATER THAN DATA FOR OFF INCIDENCE   PGM10972
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     1CALCULATIONS, A VALUE FOR DELTA INCIDENCE IS TAKEN FOR P/C=1'/' ',        PGM10973
     2' FOR ROW',I3,' STAGE',I3)                                                PGM10974
      IF(A2.GT.70.)DELTSI=B1570(5)                                              PGM10975
      IF(A2.LT.70.)DELTSI=B1570(5)                                              PGM10976
      IF(A2.LT.60.)DELTSI=B1560(5)                                              PGM10977
      IF(A2.LT.50.)DELTSI=B1550(5)                                              PGM10978
      IF(A2.LT.40.)DELTSI=B1540(5)                                              PGM10979
16    SI=DELTSI+SI751                                                           PGM10980
      SIR=CINCI/SI                                                              PGM10981
      IF((SIR.GT.1.5).OR.(SIR.LT.-4.))GO TO 17                                  PGM10982
      CALL FIG(7,YP2A,YP2B,SIR,YPC)                                             PGM10983
      YP=YP*YPC                                                                 PGM10984
      GO TO 18                                                                  PGM10985
17    YP=YP*10.                                                                 PGM10986
      WRITE(KK,29)J,K                                                           PGM10987
29    FORMAT(' ',' THE DATA LIMITS WERE EXCEEDED IN ROW',I3,' STAGE',I3)        PGM10988
18    A6=ANGIN*PI/180.                                                          PGM10989
      IF(J.EQ.1)A6=-A6                                                          PGM10990
      A4=ANGOUT*PI/180.                                                         PGM10991
      IF(J.EQ.2)A4=-A4                                                          PGM10992
      ANGMEN=ATAN(.5*(TAN(A4)-TAN(A6)))                                         PGM10993
      CLSC=2.*(TAN(A6)+TAN(A4))*COS(ANGMEN)                                     PGM10994
      ZETA=CLSC**2*(COS(A4)**2/COS(ANGMEN)**3)                                  PGM10995
      YS=.0334*(COS(A4)/COS(B1))*ZETA/ASPECR                                    PGM10996
      IF(KLEAR.EQ.1)B=.0                                                        PGM10997
      IF(KLEAR.EQ.2)B=.37                                                       PGM10998
      IF(KLEAR.EQ.3)B=.47                                                       PGM10999
      YK=B*(TIPCLA/CHORD)**.78*ZETA/ASPECR                                      PGM11000
      IF(REMACH.GT.1.)YP=YP*(1.+60.*(REMACH-1.)**2)                             PGM11001
      YPS=(YP+YS)*(RE/2.E5)**(-.2)                                              PGM11002
      YT=YPS+YK                                                                 PGM11003
      CALL FIG(7,TEX,TEY,TET,YPEC)                                              PGM11004
      YT=YT*YPEC                                                                PGM11005
24    RETURN                                                                    PGM11006
25    YT=0.5                                                                    PGM11007
      WRITE(KK,26)J,K                                                           PGM11008
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26    FORMAT(' ','THE INPUT DATA WAS GREATER THAN LIMITS OF PROGRAM & A        PGM11009
     1VALUE OF YT=.5 WAS ASSIGNED FOR ROW',I2,' STAGE',I3)                     PGM11010
      GO TO 24                                                                 PGM11011
      END                                                                      PGM11012
      FUNCTION REACT2(A,B)                                                     PGM11013
      COMMON PI,GO,RJ,HJ,GAMMA,VX,SOMEGA,DHOS,CP,GAMMA2,GAMMA1,KK              PGM11014
C COMPUTES REACTION OF ROTOR AT STATION 2                                      PGM11015
      REACT2=1.+DHOS*GO*HJ/((SOMEGA*A)**2*2.)-(VX/(SOMEGA*A))*TAN(B)           PGM11016
      RETURN                                                                   PGM11017
      END                                                                      PGM11018
      SUBROUTINE SECMOD(SMTANG,TC,SM,AREAC2)                                   PGM11019
      COMMON PI,GO,RJ,HJ,GAMMA,VX,SOMEGA,DHOS,CP,GAMMA2,GAMMA1,KK              PGM11020
      REAL A(10),B(10),C(10),N,D(8),E(8)                                       PGM11021
      DATA A/10.,20.,30.,40.,50.,60.,80.,100.,120.,140./                       PGM11022
      DATA B/1.9417,1.8561,1.7705,1.6849,1.5992,1.5136,1.3424,1.1712,1.,       PGM11023
     1.8288/                                                                   PGM11024
      DATA C/1048.5,1024.2,991.52,946.67,896.36,827.879,661.212,458.788,       PGM11025
     1270.30,66.67/                                                            PGM11026
      DATA D/0.,20.,40.,60.,80.,100.,120.,140./                                PGM11027
      DATA E/.02131,.04,.06423,.09525,.13097,.1695,.21305,.25692/              PGM11028
      I=10                                                                     PGM11029
      CALL FIG(I,A,B,SMTANG,N)                                                 PGM11030
      CALL FIG(I,A,C,SMTANG,X)                                                 PGM11031
      SM=(1./X)*(10.*TC)**N*2.25                                               PGM11032
      CALL FIG(8,D,E,SMTANG,AREAC2)                                            PGM11033
      RETURN                                                                   PGM11034
      END                                                                      PGM11035
      SUBROUTINE STOCRA(ANGLIN,ANGLOT,PCRAT)                                   PGM11036
      COMMON PI,GO,RJ,HJ,GAMMA,VX,SOMEGA,DHOS,CP,GAMMA2,GAMMA1,KK              PGM11037
      DIMENSION A40(5),B40(5),A50(4),B50(4),A(8),B(8),C(9),D(8),E(7),F(7       PGM11038
     1),G(6),H(6),X(5),Y(5)                                                    PGM11039
      DATA B40/40.,50.,60.,67.817,70./                                         PGM11040
      DATA B50/50.,60.,67.817,70./                                             PGM11041
      DATA A/0.,10.,20.,30.,40.,50.,60.,70./                                   PGM11042
      DATA B/.72759,.71675,.68719,.65961,.62611,.58966,.55517,.53153/          PGM11043
      DATA C/0.,10.,20.,30.,40.,50.,60.,70./                                   PGM11044
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```
      DATA D/.75517,.74138,.71478,.68325,.64375,.61527,.57980,.55419/    PGM11045
      DATA E/0.,10.,20.,30.,40.,50.,60./                                 PGM11046
      DATA F/.83399,.81626,.79458,.76108,.71675,.68719,.64581/           PGM11047
      DATA G/0.,10.,20.,30.,40.,50./                                     PGM11048
      DATA H/.90985,.88424,.85074,.81626,.76995,.74138/                  PGM11049
      DATA X/0.,10.,20.,30.,40./                                         PGM11050
      DATA Y/.96601,.93547,.89015,.84778,.78571/                         PGM11051
      IF(ANGLOT.GT.70.)GO TO 3                                           PGM11052
      IF((ANGLOT.GE.67.817).AND.(ANGLIN.LE.70.))GO TO 4                  PGM11053
      IF((ANGLOT.GE.60.).AND.(ANGLIN.LE.60.))GO TO 5                     PGM11054
      IF((ANGLOT.GE.50.).AND.(ANGLIN.LE.50.))GO TO 6                     PGM11055
      IF((ANGLOT.GE.40.).AND.(ANGLIN.LE.40.))GO TO 7                     PGM11056
3     CALL FIG(8,A,B,ANGLIN,PCRAT)                                       PGM11057
      GO TO 2                                                            PGM11058
4     CALL FIG(8,C,D,ANGLIN,A681)                                        PGM11059
      CALL FIG(8,A,B,ANGLIN,A682)                                        PGM11060
      PCRAT=A681-(A681-A682)*(70.-ANGLOT)/2.183                          PGM11061
      GO TO 2                                                            PGM11062
5     CALL FIG(7,E,F,ANGLIN,A601)                                        PGM11063
      CALL FIG(8,C,D,ANGLIN,A602)                                        PGM11064
      PCRAT=A601-(A601-A602)*(70.-ANGLOT)/10.                            PGM11065
      GO TO 2                                                            PGM11066
6     CALL FIG(6,G,H,ANGLIN,A50(1))                                      PGM11067
      CALL FIG(7,E,F,ANGLIN,A50(2))                                      PGM11068
      CALL FIG(8,C,D,ANGLIN,A50(3))                                      PGM11069
      CALL FIG(8,A,B,ANGLIN,A50(4))                                      PGM11070
      CALL FIG(4,B50,A50,ANGLOT,PCRAT)                                   PGM11071
      GO TO 2                                                            PGM11072
7     CALL FIG(5,X,Y,ANGLIN,A40(1))                                      PGM11073
      CALL FIG(6,G,H,ANGLIN,A40(2))                                      PGM11074
      CALL FIG(7,E,F,ANGLIN,A40(3))                                      PGM11075
      CALL FIG(8,C,D,ANGLIN,A40(4))                                      PGM11076
      CALL FIG(8,A,B,ANGLIN,A40(5))                                      PGM11077
      CALL FIG(5,B40,A40,ANGLOT,PCRAT)                                   PGM11078
2     RETURN                                                             PGM11079
      END                                                                PGM11080
```

```
      SUBROUTINE BLADE(A,B,C,J)                                          PGM11081
C CALCULATES BLADE OR GAS ANGLES FOR ROTOR AND STATORS                   PGM11082
      DIMENSION D(6),F(6)                                                PGM11083
      DATA D/24.34,40.,50.,60.,70.,80./                                  PGM11084
      DATA F/30.,47.717,53.962,62.453,70.943,78.868/                     PGM11085
      I=6                                                                PGM11086
      IF(J.EQ.2)GO TO 3                                                  PGM11087
      IF(B.LT.1.)GO TO 1                                                 PGM11088
      C=A                                                                PGM11089
      GO TO 2                                                            PGM11090
1     CALL FIG(I,D,F,A,C)                                                PGM11091
      IF(B.LT.0.5)GO TO 2                                                PGM11092
      C=C-((B-.5)/.5)*(C-A)                                              PGM11093
2     RETURN                                                             PGM11094
3     IF(B.LT.1.)GO TO 5                                                 PGM11095
      A=C                                                                PGM11096
      GO TO 2                                                            PGM11097
5     CALL FIG(6,F,D,C,A)                                                PGM11098
      IF(B.LT.0.5)GO TO 2                                                PGM11099
      A=A+((B-.5)/.5)*(C-A)                                              PGM11100
      GO TO 2                                                            PGM11101
      END                                                                PGM11102
      SUBROUTINE FIG(I,D,F,X,Y)                                          PGM11103
      DIMENSION D(I),F(I),DD(100),FF(100),A(4),B(4)                      PGM11104
      IF(((X.GT.D(I)).AND.(D(1).LT.D(I))).OR.((X.LT.D(1)).AND.(D(I).GT.D PGM11105
     1(1))).OR.((X.LT.D(I)).AND.(D(1).GT.D(I)).AND.(D(1).GT.D(I))).OR.(( PGM11106
     2X.GT.D(1)).AND.(D(1).GT.D(I))))GO TO 31                            PGM11107
      IF(D(1).GT.D(I))GO TO 9                                            PGM11108
17    IF(I.EQ.4)GO TO 2                                                  PGM11109
      N=I-1                                                              PGM11110
      J=2                                                                PGM11111
      IF(X.GE.D(N))GO TO 1                                               PGM11112
      IF(X.LE.D(J))GO TO 2                                               PGM11113
      L=3                                                                PGM11114
4     IF(X.LT.D(L))GO TO 3                                               PGM11115
      L=L+1                                                              PGM11116
```

```
      GO TO 4                                                           PGM11117
3     L=L-2                                                             PGM11118
      DO 8 K=1,4                                                        PGM11119
      A(K)=D(L)                                                         PGM11120
      B(K)=F(L)                                                         PGM11121
8     L=L+1                                                             PGM11122
      GO TO 7                                                           PGM11123
1     IJ=I-4                                                            PGM11124
      DO 5 II=1,4                                                       PGM11125
      A(II)=D(IJ)                                                       PGM11126
      B(II)=F(IJ)                                                       PGM11127
5     IJ=IJ+1                                                           PGM11128
      GO TO 7                                                           PGM11129
2     DO 6 II=1,4                                                       PGM11130
      A(II)=D(II)                                                       PGM11131
6     B(II)=F(II)                                                       PGM11132
7     CALL BK(A,B,X,Y)                                                  PGM11133
32    RETURN                                                            PGM11134
9     DD(1)=D(I)                                                        PGM11135
      FF(1)=F(I)                                                        PGM11136
      J=I                                                               PGM11137
      DO 15 M=2,I                                                       PGM11138
      J=J-1                                                             PGM11139
      DD(M)=D(J)                                                        PGM11140
15    FF(M)=F(J)                                                        PGM11141
      DO 16 M=1,I                                                       PGM11142
      D(M)=DD(M)                                                        PGM11143
16    F(M)=FF(M)                                                        PGM11144
      GO TO 17                                                          PGM11145
31    IF(((X.GT.D(I)).AND.(D(1).LT.D(I))).OR.((X.LT.D(I)).AND.(D(1).GT.D PGM11146
     1(I))))Y=F(I)                                                      PGM11147
      IF(Y.NE.F(I))Y=F(1)                                               PGM11148
      GO TO 32                                                          PGM11149
      END                                                               PGM11150
      SUBROUTINE BK(X,Y,XARG,YOUT)                                      PGM11151
      DIMENSION X(4),Y(4)                                               PGM11152
```

```
      YOUT=0.0                                                          PGM11153
      XSQ=XARG**2                                                       PGM11154
      XCU=XSQ*XARG                                                      PGM11155
      DO 10 K=1,4                                                       PGM11156
      PI1=1.                                                            PGM11157
      PI2=1.                                                            PGM11158
      SUM1=0.0                                                          PGM11159
      SUM2=0.0                                                          PGM11160
      DO 20 J=1,4                                                       PGM11161
      IF(J.EQ.K) GO TO 20                                               PGM11162
      PI1=PI1*(X(K)-X(J))                                               PGM11163
      SUM1=SUM1+X(J)                                                    PGM11164
      PI2=PI2*X(J)                                                      PGM11165
      DO 99 I=2,4                                                       PGM11166
      IF(I.EQ.K) GO TO 99                                               PGM11167
      IF(I.LE.J) GO TO 99                                               PGM11168
      SUM2=SUM2+X(J)*X(I)                                               PGM11169
99    CONTINUE                                                          PGM11170
20    CONTINUE                                                          PGM11171
10    YOUT=YOUT+1./PI1*(XCU-SUM1*XSQ+SUM2*XARG-PI2)*Y(K)                PGM11172
      IF((Y(1).GE.Y(2)).AND.(Y(2).GE.Y(3)).AND.(Y(3).GE.Y(4)).AND.(XARG.PGM11173
     1LE.X(2)).AND.((YOUT.GT.Y(1)).OR.(YOUT.LT.Y(2)))) YOUT=Y(1)-(Y(1)-Y(PGM11174
     12))*(XARG-X(1))/(X(2)-X(1))                                       PGM11175
      IF((Y(1).GE.Y(2)).AND.(Y(2).GE.Y(3)).AND.(Y(3).GE.Y(4)).AND.(XARG.PGM11176
     1LE.X(3)).AND.(XARG.GT.X(2)).AND.((YOUT.GT.Y(2)).OR.(YOUT.LT.Y(3)))PGM11177
     2) YOUT=Y(2)-(Y(2)-Y(3))*(XARG-X(2))/(X(3)-X(2))                   PGM11178
      IF((Y(1).GE.Y(2)).AND.(Y(2).GE.Y(3)).AND.(Y(3).GE.Y(4)).AND.(XARG.PGM11179
     1LE.X(4)).AND.(XARG.GT.X(3)).AND.((YOUT.GT.Y(3)).OR.(YOUT.LT.Y(4)))PGM11180
     2) YOUT=Y(3)-(Y(3)-Y(4))*(XARG-X(3))/(X(4)-X(3))                   PGM11181
      IF((Y(1).LE.Y(2)).AND.(Y(2).LE.Y(3)).AND.(Y(3).LE.Y(4)).AND.(XARG.PGM11182
     1LE.X(2)).AND.((YOUT.LT.Y(1)).OR.(YOUT.GT.Y(2)))) YOUT=Y(1)-(Y(1)-Y(PGM11183
     12))*(XARG-X(1))/(X(2)-X(1))                                       PGM11184
      IF((Y(1).LE.Y(2)).AND.(Y(2).LE.Y(3)).AND.(Y(3).LE.Y(4)).AND.(XARG.PGM11185
     1LE.X(3)).AND.(XARG.GT.X(2)).AND.((YOUT.LT.Y(2)).OR.(YOUT.GT.Y(3)))PGM11186
     2) YOUT=Y(2)-(Y(2)-Y(3))*(XARG-X(2))/(X(3)-X(2))                   PGM11187
      IF((Y(1).LE.Y(2)).AND.(Y(2).LE.Y(3)).AND.(Y(3).LE.Y(4)).AND.(XARG.PGM11188
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     1LE.X(4)).AND.(XARG.GT.X(3)).AND.((YOUT.LT.Y(3)).OR.(YOUT.GT.Y(4)))
     2) YOUT=Y(3)-(Y(3)-Y(4))*(XARG-X(3))/(X(4)-X(3))
      RETURN
      END
      SUBROUTINE TESTP(I,N)
C DETERMINES IF AN INTEGER IS A PRIME NO. GIVES AN OUTPUT OF 1 IF PRIME 0 IF NOT
      INTEGER TEST
      I=0
      TEST=2
      IF(N/TEST*TEST.NE.N)GO TO 8
      GO TO 11
8     TEST=1
3     TEST=TEST+2
      IF((N/TEST*TEST.EQ.N).AND.(TEST.NE.N))GO TO 11
      IF(TEST.EQ.N)GO TO 10
      GO TO 3
10    I=1
11    RETURN
      END
      FUNCTION REACTI(A,B)
C COMPUTES REACTION OF ROTOR AT STATION 3
      COMMON PI,GO,PJ,HJ,GAMMA,VX,SOMEGA,DHOS,CP,GAMMA2,GAMMA1,KK
      REACTI=1.-DHOS*GO*HJ/((SOMEGA*A)**2*2.)-(VX/(SOMEGA*A))*TAN(B)
      RETURN
      END
      SUBROUTINE TPD2(A,B,C,D,E,F,G,H)
C DETERMINES TEMPERATURE,PRESSURE, AND DENSITY AT STATION 2
      COMMON PI,GO,PJ,HJ,GAMMA,VX,SOMEGA,DHOS,CP,GAMMA2,GAMMA1,KK
      V=VX/COS(G)
      IF(V.LT.0.0) V=-V
      C=A-V**2/(CP*GO*HJ*2.)
      IF(C.LT.0.5*A)C=0.5*A
      F=E*(C/B)**GAMMA2
      D=F*(A/C)**GAMMA1
      H=F/(C*PJ)
      RETURN
```

```
      END                                                               PGM11225
      SUBROUTINE TP1(A,B,C,D,E,F)                                       PGM11226
C COMPUTES TEMPERATURE,PRESSURE, AND DENSITY AT STATION 1 AND 3         PGM11227
      COMMON PI,GO,RJ,HJ,GAMMA,VX,SOMEGA,DHOS,CP,GAMMA2,GAMMA1,KK       PGM11228
      V=VX/COS(C)                                                       PGM11229
      IF(V.LT.0.0) V=-V                                                 PGM11230
      B=A-V**2/(CP*GO*HJ*2.)                                            PGM11231
      IF(B.LT.0.5*A) B=0.5*A                                            PGM11232
      E=D*(B/A)**GAMMA1                                                 PGM11233
      F=E/(RJ*B)                                                        PGM11234
      RETURN                                                            PGM11235
      END                                                               PGM11236
      FUNCTION ANGLE2(A,B)                                              PGM11237
C DETERMINES ANGLE ALPHA 2                                              PGM11238
      COMMON PI,GO,RJ,HJ,GAMMA,VX,SOMEGA,DHOS,CP,GAMMA2,GAMMA1,KK       PGM11239
      ANGLE2=ATAN(DHOS*GO*HJ/(VX*SOMEGA*A)+TAN(B))                      PGM11240
      RETURN                                                            PGM11241
      END                                                               PGM11242
      FUNCTION ANGLEB(A,B)                                              PGM11243
C DETERMINES RELATIVE ANGLE BETA                                        PGM11244
      COMMON PI,GO,RJ,HJ,GAMMA,VX,SOMEGA,DHOS,CP,GAMMA2,GAMMA1,KK       PGM11245
      ANGLEB=ATAN(TAN(A)-SOMEGA*B/VX)                                   PGM11246
      RETURN                                                            PGM11247
      END                                                               PGM11248
      SUBROUTINE DENR(A,B,C,D)                                          PGM11249
      COMMON PI,GO,RJ,HJ,GAMMA,VX,SOMEGA,DHOS,CP,GAMMA2,GAMMA1,KK       PGM11250
COMPUTES INTEGRAL OF DENSITY TIMES AREA TO GET AXIAL VELOCITY BY SIMPSON'S RULE  PGM11251
      REAL A(3),B(3)                                                    PGM11252
      DENSIT=(1./3.)*((A(3)-A(1))/2.)*(A(1)*B(1)+4.*A(2)*B(2)+A(3)*B(3))  PGM11253
      D=C/(2.*PI*DENSIT)                                                PGM11254
      RETURN                                                            PGM11255
      END                                                               PGM11256
      FUNCTION ANGLF(A,B,C)                                             PGM11257
C DETERMINES ANGLE AT ANOTHER LOCATION BY FREE VORTEX DEFINITION OF R*V(THETA)=K PGM11258
      ANGLE=ATAN(A*TAN(B)/C)                                            PGM11259
      RETURN                                                            PGM11260
```

```
      END                                                                                   PGM11261
$ENTRY                                                                                      PGM11262
9000 HP SINGLE STAGE GAS TURBINE ENGINE                                                     PGM11263
00  1   60    111.333.27159000.      119.42     .2    .02   .015 1767.8     312.48          PGM11264
1.8  .62161.418.1   20000.     50          0.289 29000000.         20000.     93000.        PGM11265
.9168.08333     1.68013000C.    .000 .292       0 0 1.25    .1                              PGM11266
0.020.040.060.080.100.120.140.160.170.200.220.240.260.280.300.320.340.360.380.40 PGM11267
0.420.440.460.480.500.520.540.560.580.600.620.640.660.680.700.720.740.760.780.80 PGM11268
0.820.840.860.880.900.920.940.960.981.001.021.041.061.081.101.121.141.161.181.20 PGM11269
 0.01811 0.03596 0.05388 0.07171 0.08945 0.10706 0.12448 0.14154 0.15885 0.17562 PGM11270
 0.19226 0.20849 0.22446 0.24049 0.25612 0.27135 0.28590 0.30026 0.31435 0.32763 PGM11271
 0.34118 0.35386 0.36627 0.37821 0.38948 0.40061 0.41108 0.42114 0.43067 0.43979 PGM11272
 0.44838 0.45669 0.46421 0.47159 0.47796 0.48433 0.49010 0.49560 0.50030 0.50459 PGM11273
 0.50815 0.51170 0.51479 0.51734 0.51948 0.52123 0.52257 0.52337 0.52391 0.52418 PGM11274
 0.52391 0.52337 0.52257 0.52136 0.51989 0.51801 0.51599 0.51358 0.51076 0.50795 PGM11275
 0.99973 0.99893 0.99760 0.99574 0.99335 0.99040 0.98700 0.98317 0.97870 0.97380 PGM11276
 0.96835 0.96260 0.95630 0.94950 0.94200 0.93440 0.92650 0.91800 0.90920 0.90030 PGM11277
 0.89080 0.88100 0.87060 0.86000 0.84950 0.83860 0.82720 0.81570 0.80400 0.79220 PGM11278
 0.78020 0.76780 0.75550 0.74270 0.73070 0.71800 0.70520 0.69140 0.67910 0.66650 PGM11279
 0.65500 0.64080 0.62760 0.61410 0.60250 0.58900 0.57550 0.56500 0.55100 0.54000 PGM11280
 0.52800 0.51700 0.50400 0.49100 0.48000 0.46820 0.45650 0.44530 0.43330 0.42250 PGM11281
 0.96151 1.91184 2.86589 3.82740 4.77028 5.72284 6.67094 7.61008 8.56787 9.50329 PGM11282
10.4528711.3666812.3132813.2673414.2288415.1456416.0475016.9941117.9034418.82024 PGM11283
19.7519220.6314421.5407722.4501023.3370924.2762525.1632126.0501926.9520727.80922 PGM11284
28.6589229.5459030.4105231.2975032.0950232.9447233.8019034.6516035.4789436.29883 PGM11285
37.0516437.9396138.7659539.6082240.3982841.1436542.0306142.7088943.4169344.16234 PGM11286
44.9822245.6903146.3611347.1735747.8518848.5972049.3425650.0282750.7438251.39229 PGM11287
400. 600. 800. 1000.1200.1400.1600.1800.2000.2200.2400.                                     PGM11288
100. 135. 166. 192. 218. 242. 264. 284. 302. 320. 338.                                      PGM11289
13673 HP SINGLE STAGE AIRCRAFT GAS TURNINE ENGINE                                           PGM11290
10  2   60    111.333.274 13673.      100.        .2    .02   .015 2960.       98.2         PGM11291
2.8  1.034 2.0 0.0  13856.     50          2.289 29000000.         45000.     93000.        PGM11292
 0.9        .1    6.    130000.    -.5  -.25        0 2 1.25 .1                           PGM11293
/*EOJ ********                                                                              PGM11294
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COMPUTER PROGRAM #2

```
$*            VICTOR ENDO MAY 9,1977
$JOB          SIPP,TIME=30
$*            VICTOR ENDO MAY 9,1977
      COMMON PI,GC,RJ,HJ,GAMMA,VX,SOMEGA,DHOS,CP,GAMMA2,GAMMA1,KK
      COMMON/AREA1/TEI,TC,TIPCLA
      DIMENSION SPRES(3,3,10),RADIUS(3,3,10),ALPHA(3,3,10),BETA(3,3,10)
      DIMENSION DEN(3),RAD(3),TTEMP(3,10),TPRES(3,10),STEMP(3,3,10)
      DIMENSION REACT(3,10),RHO(3,3,10),REALMS(3,2,10),RELMP(3,2,10),TTE
     1MPR(3,2,12),VAXIAL(3,12)
      DIMENSION RBLADE(3,2,10),SBLADE(3,2,10),CHORDR(3,2,10),SIGMAB(2,10
     1),SIGMAC(12),BLADEH(2,12),PTOCHO(2,12),ASPECR(2,12),TEM(50),V(50)
      DIMENSION SPEED(5),WDOTP(7),OMEGAB(5),POIS(7),RHOC(3,10),BETAC(3,1
     10),ALPHAC(3,10),TOTC(3,10),TSC(3,10),POC(3,10),PSC(3,10),RPOC(3,10
     3),VEL(3,10),RVEL(3,10),RMAC(100),WTAP(100),PSPT(100),VELTOT(100),P
     101PO2(7),ENTMJ(7),ENSMJ(7),PTOC(3,10),A(6),B(6)
      DIMENSION WTAP11(70),WTAP12(70),RMAC11(70),RMAC12(70),VEOT11(70),V
     1EOT12(70),PSPT11(70),PSPT12(70)
      DATA SPEED/.4,.6,.8,1.,1.1/
      DATA WDOTP/.6,.8,.9,.95,.99,1.,1.01/
      KK=6
      LL=5
      LKL=0
      READ(LL,779)CP,GO,HJ,RJ,VX,TOI,POI,E,W,KKK
779   FORMAT(F5.3,F10.4,F8.3,F10.4,F10.1,F10.1,F10.3,F5.3,F10.3,I2)
      READ(LL,780)GAMMA1,PI,SOMEGA,TEI,TC,TIPCLA,GAMMA,KLM1,KLM,KTM
780   FORMAT(F10.5,F10.8,F10.3,4F5.3,I2,I3,I2
      READ(LL,782)(((RADIUS(I,J,K),I=1,3),J=1,3),K=1,KKK)
782   FORMAT(8F10.4)
      READ(LL,781)((TTEMP(J,K),J=1,3),K=1,KKK)
781   FORMAT(8F10.1)
      READ(LL,781)((STEMP(2,J,K),J=1,3),K=1,KKK)
      READ(LL,781)((TPRES(J,K),J=1,3),K=1,KKK)
      READ(LL,781)((SPRES(2,J,K),J=1,3),K=1,KKK)
      READ(LL,782)((RHO(2,J,K),J=1,3),K=1,KKK)
      READ(LL,782)((ALPHA(2,J,K),J=1,3),K=1,KKK)
      READ(LL,782)((BETA(2,J,K),J=1,3),K=1,KKK)
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```
      READ(LL,782) ((REALMS(2,J,K),J=1,2),K=1,KKK)                       PGM20037
      READ(LL,782) ((RELMR(2,J,K),J=1,2),K=1,KKK)                        PGM20038
      READ(LL,782) ((SBLADE(2,J,K),J=1,2),K=1,KKK)                       PGM20039
      READ(LL,782) ((RBLADE(2,J,K),J=1,2),K=1,KKK)                       PGM20040
      READ(LL,782) ((CHORDP(2,J,K),J=1,2),K=1,KKK)                       PGM20041
      READ(LL,782) ((ASPECR(J,K),J=1,2),K=1,KKK)                         PGM20042
      READ(LL,782) ((PTOCHO(J,K),J=1,2),K=1,KKK)                         PGM20043
  398 LKL=LKL+1                                                          PGM20044
      IF(LKL.GT.1)GO TO 299                                              PGM20045
      READ(LL,200) (RMAC(I),I=1,60)                                      PGM20046
      READ(LL,201) (WTAP(I),I=1,60)                                      PGM20047
      READ(LL,201) (PSPT(I),I=1,60)                                      PGM20048
      READ(LL,201) (VELTOT(I),I=1,60)                                    PGM20049
  201 FORMAT(10F8.5)                                                     PGM20050
  200 FORMAT(20F4.2)                                                     PGM20051
      READ(LL,227) (TFM(I),I=1,KTM)                                      PGM20052
      READ(LL,227) (V(I),I=1,KTM)                                        PGM20053
  227 FORMAT(20F5.0)                                                     PGM20054
  299 KLM=60                                                             PGM20055
      KLM2=KLM-KLM1                                                      PGM20056
      DO 230 I=1,KLM1                                                    PGM20057
      II=I+KLM1-1                                                        PGM20058
      RMAC11(I)=RMAC(I)                                                  PGM20059
      WTAP11(I)=WTAP(I)                                                  PGM20060
      PSPT11(I)=PSPT(I)                                                  PGM20061
      VEOT11(I)=VELTOT(I)                                                PGM20062
      IF(I.GT.KLM2)GO TO 230                                             PGM20063
      RMAC12(I)=RMAC(II)                                                 PGM20064
      WTAP12(I)=WTAP(II)                                                 PGM20065
      PSPT12(I)=PSPT(II)                                                 PGM20066
      VEOT12(I)=VELTOT(II)                                               PGM20067
  230 CONTINUE                                                           PGM20068
      DO 350 MK=1,5                                                      PGM20069
      OMEGAB(MK)=SOMEGA*SPEED(MK)                                        PGM20070
      DO 350 MJ=1,7                                                      PGM20071
      K=1                                                                PGM20072
```

```
      BETAC(1,K)=0.0                                                    PGM20073
      ALPHAC(1,K)=0.0                                                   PGM20074
      TOTC(1,K)=TOI                                                     PGM20075
      TSC(1,K)=TOI-VX**2/(2.*CP*HJ*GO)                                  PGM20076
      POC(1,K)=POI                                                      PGM20077
      PSC(1,K)=POC(1,K)/(TOTC(1,K)/TSC(1,K))**GAMMA1                    PGM20078
      VAXIAL(1,K)=VX                                                    PGM20079
      RHOC(1,K)=PSC(1,K)/(TSC(1,K)*RJ)                                  PGM20080
      PO1=POC(1,K)                                                      PGM20081
      TO1=TOI                                                           PGM20082
      GANG1=0.0                                                         PGM20083
  308 J=1                                                               PGM20084
  306 L=J+1                                                             PGM20085
      JJ=0                                                              PGM20086
      U=OMEGAB(MK)*RADIUS(2,L,K)                                        PGM20087
      RHO2=RHO(2,L,K)                                                   PGM20088
      RMAC2=.2*REALMS(2,2,K)                                            PGM20089
      IF(J.EQ.2) RMAC2=.2*RELMR(2,2,K)                                  PGM20090
      BLADE2=SBLADE(2,2,K)                                              PGM20091
      IF(J.EQ.2) BLADE2=RBLADE(2,2,K)                                   PGM20092
      ANNULA=PI*(RADIUS(3,L,K)**2-RADIUS(1,L,K)**2)                     PGM20093
  300 JJ=JJ+1                                                           PGM20094
      IF(J.EQ.2) BLADE2=-BLADE2                                         PGM20095
      CALL BLADE(GANG2,RMAC2,BLADE2,2)                                  PGM20096
      IF(J.EQ.2) GANG2=-GANG2                                           PGM20097
      IF(J.EQ.2) BLADE2=-BLADE2                                         PGM20098
      CALL FIG(KLM,RMAC,VELTOT,RMAC2,VELTOT2)                           PGM20099
      V2=SQRT(TO1)*VELTOT2                                              PGM20100
      CALL FIG(KLM,RMAC,PSPT,RMAC2,PSPT2)                               PGM20101
      T2=TO1*PSPT2**(1./GAMMA1)                                         PGM20102
      BLADE1=SBLADE(2,1,K)                                              PGM20103
      IF(J.EQ.2) BLADE1=RBLADE(2,1,K)                                   PGM20104
      IF(J.EQ.1) KLEAR=1                                                PGM20105
      IF(J.EQ.2) KLEAR=3                                                PGM20106
      CALL PLOSS(GANG1,GANG2,RHO2,T2,BLADE1,PTCCHC(J,K),ASPECR(J,K),RMACPGM20107
     12,V2,CHORDR(2,J,K),J,K,KLEAR,YT,KTM,TEM,V)                        PGM20108
```

```
      PO2=PO1/(YT*(1.-PSPT2)+1.)                                        PGM20109
      Q2=WDOTP(MJ)*W*SQRT(TO1)/(ANNULA*COS(GANG2*PI/180.)*PO2)          PGM20110
      IF(Q2.GT.WTAP(KLM1))Q2=WTAP(KLM1)*.99                             PGM20111
      IF(RMAC2.GT.RMAC(KLM1))GO TO 316                                  PGM20112
      CALL FIG(KLM1,WTAP11,RMAC11,Q2,RMAC2P)                            PGM20113
      CALL FIG(KLM1,WTAP11,PSPT11,Q2,PSPT2)                             PGM20114
      CALL FIG(KLM1,WTAP11,VEOT11,Q2,VETOT2)                            PGM20115
      GO TO 317                                                         PGM20116
316   CONTINUE                                                          PGM20117
      CALL FIG(KLM2,WTAP12,RMAC12,Q2,RMAC2P)                            PGM20118
      CALL FIG(KLM2,WTAP12,PSPT12,Q2,PSPT2)                             PGM20119
      CALL FIG(KLM2,WTAP12,VEOT12,Q2,VETOT2)                            PGM20120
317   PO2=PO1/(YT*(1.-PSPT2)+1.)                                        PGM20121
      P2=PO2*PSPT2                                                      PGM20122
      IF(PSPT2.LT.0.0)GO TO 399                                         PGM20123
      T2=TO1*PSPT2**(1./GAMMA1)                                         PGM20124
      RHO2=P2/(T2*RJ)                                                   PGM20125
      V2=SQRT(TO1)*VETOT2                                               PGM20126
      IF(ABS(RMAC2P/RMAC2-1.).LE.E)GO TO 302                            PGM20127
      IF((RMAC2P.GT.0.9).AND.(JJ.GT.3))GO TO 304                        PGM20128
315   IF(JJ.EQ.10)GO TO 302                                             PGM20129
      IF(ABS(RMAC2P/RMAC2-1.).LT.0.03)GO TO 318                         PGM20130
      RMAC2=RMAC2P                                                      PGM20131
      GO TO 300                                                         PGM20132
318   RMAC2=RMAC2+(RMAC2P-RMAC2)/2.                                     PGM20133
      GO TO 300                                                         PGM20134
304   Q2PRIM=1.0001*Q2                                                  PGM20135
      IF((RMACP.GT.1.0))GO TO 330                                       PGM20136
      CALL FIG(KLM1,WTAP11,PSPT11,Q2PRIM,PSPTR)                         PGM20137
      GO TO 331                                                         PGM20138
330   CALL FIG(KLM2,WTAP12,PSPT12,Q2PRIM,PSPTR)                         PGM20139
331   PO2PO1=1./(YT*(1.-PSPTR)+1.)                                      PGM20140
      WPRIME=Q2PRIM*PO2PO1*ANNULA*COS(GANG2*PI/180.)*PO1/SQRT(TO1)      PGM20141
      IF(WPRIME.LT.W*WDOTI(MJ))GO TO 305                                PGM20142
      GO TO 315                                                         PGM20143
305   WRITE(KK,310)J,K,SPEED(MK),POI/144.                               PGM20144
```

```
310   FORMAT(' ','ROW',I2,' IN STAGE',I3,' FOR N/SQRT(TO1) = ',F4.1,' FO
     1R PO1 = ',F8.1,' CHCKED')
      CALL FIG(KLM2,WTAP12,VEOT12,Q2,VEIOT2)
      CALL FIG(KLM2,WTAP12,PSPT12,Q2,PSPT2)
      V2=SQRT(TO1)*VEIOT2
      PO2=PO1/(YT*(1.-PSPT2)+1.)
      T2=TO1*PSPT2**(1./GAMMA1)
      P2=PO2*PSPT2
      RHO2=P2/(T2*RJ)
      GANG2=ARCOS(W*WDOTP(MJ)*SQRT(TO1)/(PO2*Q2*ANNULA))*180./PI
302   IF(J.EQ.2)GO TO 307
      J=J+1
      ALPHAC(2,K)=GANG2
      BETAC(2,K)=(ATAN(TAN(GANG2*PI/180.)-U/(V2*COS(GANG2*PI/180.))))*18
     10./PI
      RHOC(2,K)=RHO2
      VWSQ=(V2*COS(GANG2*PI/180.))**2*(1.+(TAN(BETAC(2,K)*PI/180.))**2)
      VAXIAL(2,K)=V2*COS(GANG2*PI/180.)
      TOTC(2,K)=TO1
      TSC(2,K)=TO1-V2**2/(2.*CP*HJ*GO)
      TO1=T2+VWSQ/(2.*CP*HJ*GO)
      PSC(2,K)=P2
      POC(2,K)=PO2
      RVTOTR=SQRT(VWSQ)/SQRT(TO1)
      CALL FIG(KLM,VEITOT,PSPT,RVTOTR,PSPT2)
      PO1=P2/PSPT2
      GANG1=BETAC(2,K)
      GO TO 306
307   TSC(3,K)=TO1-V2**2/(2.*GO*HJ*CP)
      PSC(3,K)=PO2*PSPT2
      RHOC(3,K)=RHO2
      BETAC(3,K)=GANG2
      U=OMEGAB(MK)*RADIUS(2,3,K)
      VAXIAL(3,K)=V2*COS(GANG2*PI/180.)
      ALPHAC(3,K)=(ATAN(TAN(GANG2*PI/180.)+U/(V2*COS(GANG2*PI/180.))))*1
     180./PI
```

```
      VELSQ=(V2*COS(GANG2*PI/180.))**2*(1.+TAN(ALPHAC(3,K)*PI/180.)**2)         PGM20181
      TOTC(3,K)=TSC(3,K)+VELSQ/(2.*GO*HJ*CP)                                    PGM20182
      POC(3,K)=PSC(3,K)*(TOTC(3,K)/TSC(3,K))**GAMMA1                            PGM20183
      IF(K.EQ.KKK)GO TO 309                                                     PGM20184
      L=K                                                                       PGM20185
      K=K+1                                                                     PGM20186
      ALPHAC(1,K)=ALPHAC(3,L)                                                   PGM20187
      BETAC(1,K)=BETAC(3,L)                                                     PGM20188
      TOTC(1,K)=TOTC(3,L)                                                       PGM20189
      TSC(1,K)=TSC(3,L)                                                         PGM20190
      POC(1,K)=POC(3,L)                                                         PGM20191
      PSC(1,K)=PSC(3,L)                                                         PGM20192
      VAXIAL(1,K)=VAXIAL(3,L)                                                   PGM20193
      RHOC(1,K)=RHOC(3,L)                                                       PGM20194
      GANG1=ALPHAC(1,K)                                                         PGM20195
      TO1=TOTC(1,K)                                                             PGM20196
      PO1=POC(1,K)                                                              PGM20197
      GO TO 308                                                                 PGM20198
309   PO1PO2(MJ)=POI/POC(3,KKK)                                                 PGM20199
      ENTMJ(MJ)=(TOTC(1,1)-TOTC(3,KKK))/(TOTC(1,1)*(1.-(POC(3,KKK)/POC(1        PGM20200
     1,1))**(1./GAMMA1)))                                                       PGM20201
      ENSMJ(MJ)=(TOTC(1,1)-TOTC(3,KKK))/(TOTC(1,1)*(1.-(PSC(3,KKK)/POC(1        PGM20202
     1,1))**(1./GAMMA1)))                                                       PGM20203
      WRITE(KK,311)SPEED(MK),PO1PO2(MJ)                                         PGM20204
311   FORMAT('0','FOR DESIGN POINT CALCULATIONS AT MEAN RADIUS A LIST OF        PGM20205
     1 CYCLE CALCULATIONS WILL BE COMPARED WITH PERFORMANCE'/' ','CALCUL        PGM20206
     2ATIONS OF IMPROVED AINSLEY MATHIESON METHOD 1ST COLUMN IS CYCLE CAL       PGM20207
     3CULATIONS AT DESIGN POINT'/' ','FOR N/SQRT(TO1)=',F5.2,' PO1/PO2='        PGM20208
     3,F5.2)                                                                    PGM20209
      WRITE(KK,345)                                                             PGM20210
345   FORMAT(' ','STAGE  VX STATION 1  VX STATION 2  VX STATION 3')             PGM20211
      WRITE(KK,344)(K1,(VAXIAL(J1,K1),J1=1,3),K1=1,KKK)                         PGM20212
344   FORMAT(' ',I4,3F13.0)                                                     PGM20213
      WRITE(KK,312)                                                             PGM20214
312   FORMAT('0','STATION  STAGE  TOTAL TEMPERATURE  STATIC TEMP(R)  TOT        PGM20215
     1AL PRES(PSI)  STATIC PRES(PSI)  DENSITY(LB/FT**3)  ALPHA    BETA')        PGM20216
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313   FORMAT(' ',I4,I8,F11.1,F8.1,F10.1,F8.1,F9.1,F7.1,F9.1,F7.1,6X,2F6.     PGM20217
     13,4F6.1)                                                              PGM20218
      DO 320 K1=1,KKK                                                       PGM20219
      DO 320 J1=1,3                                                         PGM20220
      TPRES2=TPRES(J1,K1)/144.                                              PGM20221
      TPRESC=POC(J1,K1)/144.                                                PGM20222
      SPRES2=SPRES(2,J1,K1)/144.                                            PGM20223
      SPRESC=PSC(J1,K1)/144.                                                PGM20224
      IF((J1.EQ.3).AND.(K1.NE.KKK))GO TO 320                                PGM20225
      WRITE(KK,313)J1,K1,TTEMP(J1,K1),TOTC(J1,K1),STEMP(2,J1,K1),TSC(J1,    PGM20226
     1K1),TPRES2,TPRESC,SPRES2,SPRESC,RHO(2,J1,K1),RHOC(J1,K1),ALPHA(2,J    PGM20227
     11,K1),ALPHAC(J1,K1),BETA(2,J1,K1),BETAC(J1,K1)                        PGM20228
320   CONTINUE                                                              PGM20229
      IF(MJ.NE.7)GO TO 350                                                  PGM20230
      WRITE(KK,326)SPEED(MK)                                                PGM20231
326   FORMAT('0','FOR N/SQRT(TO1) EQUAL TO ',F5.2)                          PGM20232
      WRITE(KK,328)                                                         PGM20233
328   FORMAT('0',' PO1/PO2  TOTAL EFFICIENCY  STATIC EFFICIENCY  M*SQRT(    PGM20234
     1TO1)/PO1')                                                            PGM20235
      WRITE(KK,327)(PO1PO2(I),ENTMJ(I),ENSMJ(I),WDOTP(I),I=1,7)             PGM20236
327   FORMAT(' ',F7.2,F15.4,F18.4,F17.3)                                    PGM20237
350   CONTINUE                                                              PGM20238
399   IF(LKL.LT.4)GO TO 398                                                 PGM20239
      STOP                                                                  PGM20240
      END                                                                   PGM20241
      SUBROUTINE PLOSS(ANGIN,ANGOUT,RHO,TEMP,BLADIN,PTOCHO,ASPECR,RMACH     PGM20242
     1,VELOT,CHORD,J,K,KLFAR,YT,KTM,TEM,U)                                  PGM20243
      COMMON PI,GO,PJ,HJ,GAMMA,VX,SOMEGA,DHOS,CP,GAMMA2,GAMMA1,KK           PGM20244
      COMMON/AREA1/TET,TC,TIPCLA                                            PGM20245
      DIMENSION B180(9),B275(9),A3(9),B370(9),B365(9),B360(9),B350(9),B3    PGM20246
     140(9),A5(5),B5(5),A15(5),B1540(5),B1550(5),B1560(5),B1570(5),A7(7)    PGM20247
     1,B7(7),A811(11),B865(11),B860(11),B855(11),B850(11),B840(11),A8(9)    PGM20248
     3,B830(9),PCA(7),PCB(7),YP2A(7),YP2B(7),TEX(7),TEY(7),ANG80(7),ANG7    PGM20249
     40(6),ANG30(7),YPIA(6),YPNA(7),SI75(7),ANG47(4),SIDA(4),AI(9),TEM(K    PGM20250
     5TM),U(KTM),BI70(9),BI65(9),BI60(9),BI55(9),BI50(9),BI40(9)            PGM20251
      DATA A3/.3,.4,.5,.6,.7,.8,.9,1.,1.1/                                  PGM20252
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      DATA B180/.07149,.06468,.0594,.05883,.06128,.06553,.07285,.0834,.0    PGM20253
     19532/                                                                 PGM20254
      DATA B275/.06979,.05872,.05021,.04766,.04817,.05140,.05651,.06383,    PGM20255
     1.074/                                                                 PGM20256
      DATA B370/.06894,.05532,.04511,.03966,.03830,.04,.0434,.04936,.057    PGM20257
     187/                                                                   PGM20258
      DATA B365/.06809,.05498,.04255,.03574,.03098,.02928,.03115,.03643,    PGM20259
     1.04494/                                                               PGM20260
      DATA B360/.06638,.05362,.04068,.03149,.02689,.02417,.02451,.02809,    PGM20261
     1.03404/                                                               PGM20262
      DATA B350/.06519,.05055,.03949,.0303,.02502,.02264,.02128,.02077,.    PGM20263
     102247/                                                                PGM20264
      DATA B340/.06468,.0497,.03745,.02911,.02383,.02043,.01855,.01804,.    PGM20265
     101872/                                                                PGM20266
      DATA AI/.3,.4,.5,.6,.7,.8,.9,1.,1.1/                                  PGM20267
      DATA BI70/.16113,.14186,.13640,.13981,.14868,.16193,.17596,.19096,    PGM20268
     1.2077/                                                                PGM20269
      DATA BI65/.15613,.13026,.11867,.11628,.12089,.12907,.13981,.15192,    PGM20270
     1.1668/                                                                PGM20271
      DATA BI60/.14334,.11799,.10571,.10196,.10401,.10827,.11475,.12361,    PGM20272
     1.1328/                                                                PGM20273
      DATA BI55/.14749,.11509,.09787,.08747,.08491,.08730,.09378,.10315,    PGM20274
     1.1166/                                                                PGM20275
      DATA BI50/.14408,.11168,.09122,.07843,.0731,.07502,.0798,.08781,.0    PGM20276
     1987/                                                                  PGM20277
      DATA BI40/.13981,.10656,.0861,.07315,.06581,.0653,.0682,.07398,.08    PGM20278
     1/                                                                     PGM20279
      DATA A5/.4,.5,.6,.7,.8/                                               PGM20280
      DATA B5/8.0576,6.8921,4.6043,1.4532,-2.3022/                          PGM20281
      DATA A15/.8,.85,.9,.95,1./                                            PGM20282
      DATA B1540/-2.3022,-3.3813,-4.6763,-5.5396,-6.4029/                   PGM20283
      DATA B1550/-2.3044,-4.4604,-6.6187,-8.9928,-11.3669/                  PGM20284
      DATA B1560/-2.3066,-4.7626,-8.0432,-11.3669,-14.777/                  PGM20285
      DATA B1570/-2.3088,-5.3237,-9.6403,-14.1726,-19.1367/                 PGM20286
      DATA A7/-.9,-.6,-.4,-.2,0.,.2,.4/                                     PGM20287
      DATA B7/11.218,25.671,33.437,40.988,44.223,43.576,40.34/              PGM20288
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      DATA A811/-.9,-.8,-.6,-.4,-.2,.0,.2,.4,.6,.8,1./                  PGM20289
      DATA B865/10.355,14.453,21.788,28.562,34.30,37.105,37.105,34.732,3 PGM20290
     10.503,24.808,19.199/                                               PGM20291
      DATA B860/8.025,11.563,17.387,22.435,26.318,28.993,30.547,29.899,2 PGM20292
     17.57,23.384,19.199/                                                PGM20293
      DATA B855/7.992,10.01,14.324,17.905,21.141,23.643,25.283,25.369,24 PGM20294
     1.032,21.788,19.1990/                                               PGM20295
      DATA B850/7.162,8.802,11.735,14.367,16.611,18.552,19.976,20.882,20 PGM20296
     1.796,20.192,19.631/                                                PGM20297
      DATA B840/6.04,6.903,8.845,10.355,11.865,13.289,14.626,15.532,16.4 PGM20298
     181,17.56,18.984/                                                   PGM20299
      DATA A8/-.9,-.8,-.6,-.4,-.2,0.0,.2,.4,.6/                          PGM20300
      DATA B830/4.099,5.177,6.472,7.55,8.629,9.406,10.268,10.786,11.045/ PGM20301
      DATA PCA/.4,.5,.6,.7,.8,.9,1./                                     PGM20302
      DATA PCB/1.1069,1.0784,1.0483,1.0155,.9807,.9405,.9/               PGM20303
      DATA YP2A/-4.,-3.,-2.,-1.,0.,1.,1.5/                               PGM20304
      DATA YP2B/6.1578,4.2565,2.7395,1.5663,1.,2.0922,4.5599/            PGM20305
      DATA TEX/0.,.02,.04,.06,.08,.1,.12/                                PGM20306
      DATA TFY/.91304,1.,1.1087,1.239,1.3826,1.5304,1.6913/              PGM20307
      DATA ANG80/40.,50.,60.,65.,70.,75.,80./                            PGM20308
      DATA ANG70/40.,50.,55.,60.,65.,70./                                PGM20309
      DATA ANG47/40.,50.,60.,70./                                        PGM20310
      DATA ANG30/30.,40.,50.,55.,60.,65.,70./                            PGM20311
      U1=U(KTM)                                                          PGM20312
      IF(TEMP.GT.TFM(KTM))GO TO 1                                        PGM20313
      CALL FIG(KTM,TFM,U,TEMP,U1)                                        PGM20314
    1 RE=((RHO*CHORD*VELOT)/(U1*12.))*1.E7                               PGM20315
      YPI=0.0                                                            PGM20316
      A1=ANGIN                                                           PGM20317
      IF(J.EQ.1) A1=-ANGIN                                               PGM20318
      A2=ANGOUT                                                          PGM20319
      IF(J.EQ.2) A2=-ANGOUT                                              PGM20320
      B1=BLADIN*PI/180.                                                  PGM20321
      CINCI=ANGIN-BLADIN                                                 PGM20322
      IF(J.EQ.1)CINCI=BLADIN-ANGIN                                       PGM20323
      IF((PTOCHO.LT.0.4).OR.(PTOCHO.GT.1.1))GO TO 25                     PGM20324
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      IF((ABS(ANGOUT).GT.80.).OR.(ABS(ANGOUT).LT.30.))GO TO 25          PGM20325
      IF(ABS(BLADIN).LT.0.5)GO TO 6                                     PGM20326
      IF(ABS(ANGOUT).GT.70.)GO TO 2                                     PGM20327
      IF(ABS(ANGOUT).LT.40.)GO TO 4                                     PGM20328
      CALL FIG(9,AI,BI40,PTOCHO,YPIA(1))                                PGM20329
      CALL FIG(9,AI,BI50,PTOCHO,YPIA(2))                                PGM20330
      CALL FIG(9,AI,BI55,PTOCHO,YPIA(3))                                PGM20331
      CALL FIG(9,AI,BI60,PTOCHO,YPIA(4))                                PGM20332
      CALL FIG(9,AI,BI65,PTOCHO,YPIA(5))                                PGM20333
      CALL FIG(9,AI,BI70,PTOCHO,YPIA(6))                                PGM20334
      CALL FIG(6,ANG70,YPIA,A2,YPI)                                     PGM20335
      GO TO 6                                                           PGM20336
2     WRITE(KK,3)J,K                                                    PGM20337
3     FORMAT(' ','THE ANGLE OUT WAS GREATER THAN 70 DEG AND THE DATA WAS PGM20338
     1 FROM 70 DEG FOR ROW',I3,'STAGE',I3)                              PGM20339
      GO TO 6                                                           PGM20340
4     WRITE(KK,5)J,K                                                    PGM20341
5     FORMAT(' ','THE ANGLE OUT WAS LESS    THAN 40 DEG AND THE DATA WAS PGM20342
     1 FROM 40 DEG FOR ROW',I3,'STAGE',I3)                              PGM20343
      CALL FIG(9,AI,BI40,PTOCHO,YPI)                                    PGM20344
6     IF(ABS(ANGOUT).LT.40.)GO TO 7                                     PGM20345
      CALL FIG(9,A3,B340,PTOCHO,YPNA(1))                                PGM20346
      CALL FIG(9,A3,B350,PTOCHO,YPNA(2))                                PGM20347
      CALL FIG(9,A3,B360,PTOCHO,YPNA(3))                                PGM20348
      CALL FIG(9,A3,B365,PTOCHO,YPNA(4))                                PGM20349
      CALL FIG(9,A3,B370,PTOCHO,YPNA(5))                                PGM20350
      CALL FIG(9,A3,B275,PTOCHO,YPNA(6))                                PGM20351
      CALL FIG(9,A3,B180,PTOCHO,YPNA(7))                                PGM20352
      CALL FIG(7,ANG80,YPNA,A2,YPN)                                     PGM20353
      GO TO 8                                                           PGM20354
7     WRITE(KK,5)J,K                                                    PGM20355
      CALL FIG(9,A3,B340,PTOCHO,YPN)                                    PGM20356
8     YP=(YPN+(BLADIN/ANGOUT)**2*(YPI-YPN))*(TC/.2)**(-BLADIN/ANGOUT)   PGM20357
      IF(ABS(CINCI).LT.0.5)GO TO 18                                     PGM20358
      IF(PTOCHO.GT.1.)GO TO 35                                          PGM20359
      CALL FIG(7,PCA,PCB,PTOCHO,C75)                                    PGM20360
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      GO TO 34                                                          PGM20361
35    C75=PCB(7)-.4*(PTOCHO-1.)                                         PGM20362
34    A275=A2/C75                                                       PGM20363
      AB=BLADIN/A275                                                    PGM20364
      IF(J.EQ.2) AB=-BLADIN/A275                                        PGM20365
      IF((AB.LT.-.9).OR.(AB.GT.1.)) GO TO 25                            PGM20366
      IF((A275.GT.65.).AND.(AB.GT.0.4)) GO TO 9                         PGM20367
      IF((A275.LT.40.).AND.(AB.GT.0.6)) GO TO 11                        PGM20368
      CALL FIG(9,A8,B830,AB,SI75(1))                                    PGM20369
      CALL FIG(11,A811,B840,AB,SI75(2))                                 PGM20370
      CALL FIG(11,A811,B850,AB,SI75(3))                                 PGM20371
      CALL FIG(11,A811,B855,AB,SI75(4))                                 PGM20372
      CALL FIG(11,A811,B860,AB,SI75(5))                                 PGM20373
      CALL FIG(11,A811,B865,AB,SI75(6))                                 PGM20374
      CALL FIG(7,A7,B7,AB,SI75(7))                                      PGM20375
      CALL FIG(7,ANG30,SI75,A275,SI751)                                 PGM20376
      GO TO 12                                                          PGM20377
9     WRITE(KK,10) J,K                                                  PGM20378
10    FORMAT(' ','THE ANGLE OUT WAS GREATER THAN 65 DEG AND THE DATA WAS PGM20379
     1 FROM 65 DEG FOR ROW',I3,'STAGE',I3)                              PGM20380
      CALL FIG(11,A811,B865,AB,SI751)                                   PGM20381
      GO TO 12                                                          PGM20382
11    WRITE(KK,5) J,K                                                   PGM20383
      CALL FIG(9,A8,B830,AB,SI751)                                      PGM20384
12    IF(PTOCHO.GT.0.8) GO TO 13                                        PGM20385
      CALL FIG(5,A5,B5,PTOCHO,DELTST)                                   PGM20386
      GO TO 16                                                          PGM20387
13    IF(PTOCHO.GT.1.) GO TO 14                                         PGM20388
      IF((A2.LT.40.).OR.(A2.GT.70.)) GO TO 14                           PGM20389
      CALL FIG(5,A15,B1540,PTOCHO,SIDA(1))                              PGM20390
      CALL FIG(5,A15,B1550,PTOCHO,SIDA(2))                              PGM20391
      CALL FIG(5,A15,B1560,PTOCHO,SIDA(3))                              PGM20392
      CALL FIG(5,A15,B1570,PTOCHO,SIDA(4))                              PGM20393
      CALL FIG(4,ANG47,SIDA,A2,DELTSI)                                  PGM20394
      GO TO 16                                                          PGM20395
14    WRITE(KK,15) J,K                                                  PGM20396
```

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15    FORMAT(' ','THE P/C RATIO WAS GREATER THAN DATA FOR OFF INCIDENCE       PGM20397
     1CALCULATIONS, A VALUE FOR DELTA INCIDENCE IS TAKEN FOR P/C=1'/' ',     PGM20398
     2' FOR ROW',I3,' STAGE',I3)                                              PGM20399
      IF(A2.GT.70.)DELTSI=B1570(5)                                            PGM20400
      IF(A2.LT.70.)DELTSI=B1570(5)                                            PGM20401
      IF(A2.LT.60.)DELTSI=B1560(5)                                            PGM20402
      IF(A2.LT.50.)DELTSI=B1550(5)                                            PGM20403
      IF(A2.LT.40.)DELTSI=B1540(5)                                            PGM20404
16    SI=DELTSI+SI751                                                         PGM20405
      SIR=CINCI/SI                                                            PGM20406
      IF((SIR.GT.1.5).OR.(SIR.LT.-4.))GO TO 17                                PGM20407
      CALL FIG(7,YP2A,YP2B,SIR,YPC)                                           PGM20408
      YP=YP*YPC                                                               PGM20409
      GO TO 18                                                                PGM20410
17    YP=YP*10.                                                               PGM20411
      WRITE(KK,29)J,K                                                         PGM20412
29    FORMAT(' ',' THE DATA LIMITS WERE EXCEEDED IN ROW',I3,' STAGE',I3)      PGM20413
18    A6=ANGIN*PI/180.                                                        PGM20414
      IF(J.EQ.1)A6=-A6                                                        PGM20415
      A4=ANGOUT*PI/180.                                                       PGM20416
      IF(J.EQ.2)A4=-A4                                                        PGM20417
      ANGMEN=ATAN(.5*(TAN(A4)-TAN(A6)))                                       PGM20418
      CLSC=2.*(TAN(A6)+TAN(A4))*COS(ANGMEN)                                   PGM20419
      ZETA=CLSC**2*(COS(A4)**2/COS(ANGMEN)**3)                                PGM20420
      YS=.0334*(COS(A4)/COS(B1))*ZETA/ASPECR                                  PGM20421
      IF(KLEAR.EQ.1)B=.0                                                      PGM20422
      IF(KLEAR.EQ.2)B=.37                                                     PGM20423
      IF(KLEAR.EQ.3)B=.47                                                     PGM20424
      YK=B*(TIPCLA/CHORD)**.78*ZETA/ASPECR                                    PGM20425
      IF(REMACH.GT.1.)YP=YP*(1.+60.*(REMACH-1.)**2)                           PGM20426
      YPS=(YP+YS)*(RE/2.E5)**(-.2)                                            PGM20427
      YT=YPS+YK                                                               PGM20428
      CALL FIG(7,TEX,TEY,TET,YPEC)                                            PGM20429
      YT=YT*YPEC                                                              PGM20430
24    RETURN                                                                  PGM20431
25    YT=0.5                                                                  PGM20432
```

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      WRITE(KK,26)J,K                                                   PGM20433
26    FORMAT(' ','THE INPUT DATA WAS GREATER THAN LIMITS OF PROGRAM & A PGM20434
     1VALUE OF YT=.5 WAS ASSIGNED FOR ROW',I2,' STAGE',I3)              PGM20435
      GO TO 24                                                          PGM20436
      END                                                               PGM20437
      SUBROUTINE BLADE(A,B,C,J)                                         PGM20438
C CALCULATES BLADE OR GAS ANGLES FOR ROTOR AND STATORS                  PGM20439
      DIMENSION D(6),F(6)                                               PGM20440
      DATA D/24.34,40.,50.,60.,70.,80./                                 PGM20441
      DATA F/30.,47.717,53.962,62.453,70.943,78.868/                    PGM20442
      IF(J.EQ.2)GO TO 3                                                 PGM20443
      IF(B.LT.1.)GO TO 1                                                PGM20444
      C=A                                                               PGM20445
      GO TO 2                                                           PGM20446
1     CALL FIG(6,D,F,A,C)                                               PGM20447
      IF(B.LT.0.5)GO TO 2                                               PGM20448
      C=C-((B-.5)/.5)*(C-A)                                             PGM20449
2     RETURN                                                            PGM20450
3     IF(B.LT.1.)GO TO 5                                                PGM20451
      A=C                                                               PGM20452
      GO TO 2                                                           PGM20453
5     CALL FIG(6,F,D,C,A)                                               PGM20454
      IF(B.LT.0.5)GO TO 2                                               PGM20455
      A=A+((B-.5)/.5)*(C-A)                                             PGM20456
      GO TO 2                                                           PGM20457
      END                                                               PGM20458
      SUBROUTINE FIG(I,D,F,X,Y)                                         PGM20459
      DIMENSION D(I),F(I),DD(100),FF(100),A(4),B(4)                     PGM20460
      IF(((X.GT.D(I)).AND.(D(1).LT.D(I))).OR.((X.LT.D(1)).AND.(D(I).GT.DPGM20461
     1(1))).OR.((X.LT.D(I)).AND.(D(1).GT.D(I))).AND.(D(1).GT.D(I))).OR.((PGM20462
     2X.GT.D(1)).AND.(D(1).GT.D(I))))GO TO 31                           PGM20463
      IF(D(1).GT.D(I))GO TO 9                                           PGM20464
17    IF(I.EQ.4)GO TO 2                                                 PGM20465
      N=I-1                                                             PGM20466
      J=2                                                               PGM20467
      IF(X.GE.D(N))GO TO 1                                              PGM20468
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      IF(X.LE.D(J))GO TO 2                                              PGM20469
      L=3                                                               PGM20470
 4    IF(X.LT.D(L))GO TO 3                                              PGM20471
      L=L+1                                                             PGM20472
      GO TO 4                                                           PGM20473
 3    L=L-2                                                             PGM20474
      DO 8 K=1,4                                                        PGM20475
      A(K)=D(L)                                                         PGM20476
      B(K)=F(L)                                                         PGM20477
 8    L=L+1                                                             PGM20478
      GO TO 7                                                           PGM20479
 1    IJ=I-4                                                            PGM20480
      DO 5 II=1,4                                                       PGM20481
      A(II)=D(IJ)                                                       PGM20482
      B(II)=F(IJ)                                                       PGM20483
 5    IJ=IJ+1                                                           PGM20484
      GO TO 7                                                           PGM20485
 2    DO 6 II=1,4                                                       PGM20486
      A(II)=D(II)                                                       PGM20487
 6    B(II)=F(II)                                                       PGM20488
 7    CALL BK(A,B,X,Y)                                                  PGM20489
 32   RETURN                                                            PGM20490
 9    DD(1)=D(I)                                                        PGM20491
      FF(1)=F(I)                                                        PGM20492
      J=I                                                               PGM20493
      DO 15 M=2,I                                                       PGM20494
      J=J-1                                                             PGM20495
      DD(M)=D(J)                                                        PGM20496
 15   FF(M)=F(J)                                                        PGM20497
      DO 16 M=1,I                                                       PGM20498
      D(M)=DD(M)                                                        PGM20499
 16   F(M)=FF(M)                                                        PGM20500
      GO TO 17                                                          PGM20501
 31   IF(((X.GT.D(I)).AND.(D(1).LT.D(I))).OR.((X.LT.D(I)).AND.(D(1).GT.D PGM20502
     1(I))))Y=F(I)                                                      PGM20503
      IF(Y.NE.F(I))Y=F(1)                                               PGM20504
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      GO TO 32                                                          PGM20505
      END                                                               PGM20506
      SUBROUTINE RK(X,Y,XARG,YOUT)                                      PGM20507
      DIMENSION X(4),Y(4)                                               PGM20508
      YOUT=0.0                                                          PGM20509
      XSQ=XARG**2                                                       PGM20510
      XCU=XSQ*XARG                                                      PGM20511
      DO 10 K=1,4                                                       PGM20512
      PI1=1.                                                            PGM20513
      PI2=1.                                                            PGM20514
      SUM1=0.0                                                          PGM20515
      SUM2=0.0                                                          PGM20516
      DO 20 J=1,4                                                       PGM20517
      IF(J.EQ.K)GO TO 20                                                PGM20518
      PI1=PI1*(X(K)-X(J))                                               PGM20519
      SUM1=SUM1+X(J)                                                    PGM20520
      PI2=PI2*X(J)                                                      PGM20521
      DO 99 I=2,4                                                       PGM20522
      IF(I.EQ.K)GO TO 99                                                PGM20523
      IF(I.LE.J)GO TO 99                                                PGM20524
      SUM2=SUM2+X(J)*X(I)                                               PGM20525
   99 CONTINUE                                                          PGM20526
   20 CONTINUE                                                          PGM20527
   10 YOUT=YOUT+1./PI1*(XCU-SUM1*XSQ+SUM2*XARG-PI2)*Y(K)                PGM20528
      IF((Y(1).GE.Y(2)).AND.(Y(2).GE.Y(3)).AND.(Y(3).GE.Y(4)).AND.(XARG.PGM20529
     1LE.X(2)).AND.((YOUT.GT.Y(1)).OR.(YOUT.LT.Y(2)))) YOUT=Y(1)-(Y(1)-Y(PGM20530
     12))*(XARG-X(1))/(X(2)-X(1))                                       PGM20531
      IF((Y(1).GE.Y(2)).AND.(Y(2).GE.Y(3)).AND.(Y(3).GE.Y(4)).AND.(XARG.PGM20532
     1LE.X(3)).AND.(XARG.GT.X(2)).AND.((YOUT.GT.Y(2)).OR.(YOUT.LT.Y(3)))PGM20533
     2) YOUT=Y(2)-(Y(2)-Y(3))*(XARG-X(2))/(X(3)-X(2))                   PGM20534
      IF((Y(1).GE.Y(2)).AND.(Y(2).GE.Y(3)).AND.(Y(3).GE.Y(4)).AND.(XARG.PGM20535
     1LE.X(4)).AND.(XARG.GT.X(3)).AND.((YOUT.GT.Y(3)).OR.(YOUT.LT.Y(4)))PGM20536
     2) YOUT=Y(3)-(Y(3)-Y(4))*(XARG-X(3))/(X(4)-X(3))                   PGM20537
      IF((Y(1).LE.Y(2)).AND.(Y(2).LE.Y(3)).AND.(Y(3).LE.Y(4)).AND.(XARG.PGM20538
     1LE.X(2)).AND.((YOUT.LT.Y(1)).OR.(YOUT.GT.Y(2)))) YOUT=Y(1)-(Y(1)-Y(PGM20539
     12))*(XARG-X(1))/(X(2)-X(1))                                       PGM20540
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      IF((Y(1).LE.Y(2)).AND.(Y(2).LE.Y(3)).AND.(Y(3).LE.Y(4)).AND.(YARG.        PGM20541
     1LE.X(3)).AND.(YARG.GT.X(2)).AND.((YOUT.LT.Y(2)).OR.(YOUT.GT.Y(3)))        PGM20542
     2) YOUT=Y(2)-(Y(2)-Y(3))*(XARG-X(2))/(X(3)-X(2))                           PGM20543
      IF((Y(1).LE.Y(2)).AND.(Y(2).LE.Y(3)).AND.(Y(3).LE.Y(4)).AND.(XARG.        PGM20544
     1LE.X(4)).AND.(XARG.GT.X(3)).AND.((YOUT.LT.Y(3)).OR.(YOUT.GT.Y(4)))        PGM20545
     2) YOUT=Y(3)-(Y(3)-Y(4))*(XARG-X(3))/(X(4)-X(3))                           PGM20546
      RETURN                                                                    PGM20547
      END                                                                       PGM20548
$ENTRY                                                                          PGM20549
0.271   32.1740 778.160   52.7780     439.2     1767.8 44997.1100.001   119.420 1 PGM20550
   4.003033.14159200  2094.395.02   .2  .015 1.33350 6011                       PGM20551
    0.4292    0.5179    0.6066    0.4292    0.5385    0.6478    0.4292    0.5574 PGM20552
    0.6856                                                                      PGM20553
    1767.8    1767.8    1553.8                                                  PGM20554
    1753.6    1631.3    1539.6                                                  PGM20555
   44997.1   44137.6   25526.9                                                  PGM20556
   43569.0   31708.7   24606.7                                                  PGM20557
    0.4708    0.3683    0.3028                                                  PGM20558
    0.0000   71.1965    0.0000                                                  PGM20559
  -67.9591   20.2402  -69.3845                                                  PGM20560
    0.2234    0.7090                                                            PGM20561
    0.2436    0.6681                                                            PGM20562
    0.0000   71.5782                                                            PGM20563
   20.2402  -70.0771                                                            PGM20564
    1.1894    1.2447                                                            PGM20565
    1.9973    2.2891                                                            PGM20566
    0.7279    0.7719                                                            PGM20567
0.020.040.060.080.100.120.140.160.170.200.220.240.260.280.300.320.340.360.380.40 PGM20568
0.420.440.460.480.500.520.540.560.580.600.620.640.660.680.700.720.740.760.780.80 PGM20569
0.820.840.860.880.900.920.940.960.981.001.021.041.061.081.101.121.141.161.181.20 PGM20570
 0.01811 0.03596 0.05388 0.07171 0.08945 0.10706 0.12448 0.14154 0.15885 0.17562 PGM20571
 0.19226 0.20849 0.22446 0.24049 0.25612 0.27135 0.28590 0.30026 0.31435 0.32763 PGM20572
 0.34118 0.35386 0.36627 0.37821 0.39049 0.40061 0.41108 0.42114 0.43067 0.43979 PGM20573
 0.44838 0.45669 0.46421 0.47159 0.47796 0.48433 0.49010 0.49560 0.50030 0.50459 PGM20574
 0.50815 0.51170 0.51479 0.51734 0.51948 0.52123 0.52257 0.52337 0.52391 0.52418 PGM20575
 0.52391 0.52337 0.52257 0.52136 0.51989 0.51801 0.51599 0.51358 0.51076 0.50795 PGM20576
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 0.99973 0.99893 0.99760 0.99574 0.99335 0.99040 0.98700 0.98317 0.97870 0.97380 PGM20577
 0.96835 0.96260 0.95630 0.94950 0.94200 0.93440 0.92650 0.91800 0.90920 0.90030 PGM20578
 0.89080 0.88100 0.87060 0.86000 0.84950 0.83860 0.82720 0.81570 0.80400 0.79220 PGM20579
 0.78020 0.76750 0.75550 0.74270 0.73070 0.71800 0.70520 0.69140 0.67910 0.66650 PGM20580
 0.65500 0.64080 0.62760 0.61410 0.60250 0.58900 0.57550 0.56500 0.55100 0.54000 PGM20581
 0.52800 0.51700 0.50400 0.49100 0.48000 0.46820 0.45650 0.44530 0.43330 0.42250 PGM20582
 0.96151 1.91184 2.86589 3.82740 4.77028 5.72284 6.67094 7.61008 8.56787 9.50322 PGM20583
10.4528711.3666812.3132813.2673414.2788415.1456416.0475016.9941117.9034418.83024 PGM20584
19.7519220.6314421.5407722.4501023.3370824.2762525.1632126.0501926.9520727.83922 PGM20585
28.6589229.5459030.4105231.2975032.0950232.9647233.8019034.6516035.4783436.22383 PGM20586
37.0516437.9386138.7659539.6082240.3982841.1436542.0306142.7088943.4169844.16234 PGM20587
44.9822245.6903146.3611347.1735747.8518448.5972049.3425650.0282750.7438251.39229 PGM20588
400. 600. 800. 1000.1200.1400.1600.1800.2000.2200.2400.                          PGM20589
100. 135. 166. 192. 218. 242. 264. 284. 302. 320. 338.                          PGM20590
$END                                                                             PGM20591
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Thesis 170587
E4376 Endo
Preliminary design of
a free vortex axial
flow turbine.